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THE JOURNAL OF THE SOCIETY OF AUTOMOTIVE ENGINEERS

JANUARY 1922

ANNUAL MEETING PAPERS

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THE

JOURNAL
OF THE SOCIETY OF
AUTOMOTIVE ENGINEERS

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DAVID BEECROFT, *President* COKER F. CLARKSON, *Secretary* C. B. WHITTELSEY, *Treasurer*

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THE JOURNAL OF THE SOCIETY OF AUTOMOTIVE ENGINEERS

Vol. X January, 1922 No. 1

Chicago Fuel Session

THE joint sessions in which representatives of the Society, the National Automobile Chamber of Commerce and other automotive interests conferred with members of the American Petroleum Institute at Chicago on Dec. 6 and 7 represent one of the results of consistent effort on the part of leading men in the automotive and the oil industries for the past 2 years to bring about a closer understanding and more active cooperation between these two industries in reaching solutions of some of the immensely important problems in which their interests and those of the general public are involved.

The keynote of the sessions was the necessity and practicability of uniformity and sufficient volatility of gasoline as marketed and used for motor fuel throughout the Country. After a presentation of the general economic situation by Dr. Van H. Manning for the petroleum industry and Edward S. Jordan for the automotive industry, the technical phases of the problem were discussed from various angles in a series of papers that appear hereinbelow in abstract form.

The success of the meeting in bringing about a better understanding of the real problems and difficulties of each industry by representatives of the other was obvious throughout. It was evident that a status has been reached wherein neither the petroleum refiner nor the automotive engineer is willing to speak before a technical audience without considering carefully whether his statements will stand analysis in the light of the practical limitations of the other industry.

The automotive engineer has of necessity studied the problem of proper utilization of available fuels; it was a part of his job. Therefore, prior to a recent date the problems of decreasing volatility and lack of uniformity received more attention from him than from the fuel producer. Of late there has been a rapidly increasing interest in this problem on the part of the petroleum industry, this being accompanied by gratifying research activity. The Chicago meeting constituted a conspicuous step in advance in the growing spirit of mutual understanding and cooperation between the two great industries. The technical men in them are being brought together in intimate professional discussion.

R. D. Benson, president of the Tide Water Oil Co., and Capt. J. F. Lucey, president of the Lucey Mfg. Co., had charge of the deliberations of the sessions, and as executives favored strongly the continuance of further and more intensive engineering work in the field of oil technology. It was seen how very great the need is for research in the realm of oil refining. This point was driven home by Sir John Cadman, formerly His Majesty's Petroleum Executive. The matter was stressed also by President Beecroft, of the Society.

EDWARD S. JORDAN

Mr. Jordan, president of the Jordan Motor Car Co., presented on behalf of the National Automobile Chamber of Commerce a statement as to the public's attitude toward the automobile industry and toward the little understood fuel problem, in the working out of which the engineers have had little consideration from many of the automobile producers. His address was in part as follows.

It has been said that five things are vitally essential to the welfare of the people and the progress of the Nation. The first four, food, fuel, clothing and shelter, are really necessary to life, but the distribution and general enjoyment of them depend absolutely upon the fifth, transportation.

Some of you represent an industry engaged in producing fuel. I represent an industry engaged in producing transportation. Our interests are mutual and our common obligation to the public is identical.

I have an impression that the oil industry has suffered in somewhat the same way the automobile industry has suffered, through prosperity. Engineers in our industry will tell you that the manufacturers have been so successful in past years in building what they chose to build, that they have not been careful to keep in touch with all of the engineering developments. Many of the companies have not spent much money in research work. I think that the present conditions will bring about a greater appreciation of the necessity for cooperative research work in our industry and in yours. I wish to present a certain point of view, which might be said to be a sales or a service point of view, based upon our mutual obligation to the man who is going to determine whether we can market our product and how we shall market and what price we will get for it—the owner of the automobile.

More Efficient Cars

There is a very strong tendency among manufacturers to direct their engineers to build lighter or at least more economical, more efficient cars. That is the first consideration today. It indicates an acceptance on the part of

automobile manufacturers of the fundamental need of the owner, a vehicle of necessary transportation that can be operated at the lowest possible cost.

A misapprehension still exists in the minds of many that people do not care how much they pay for service, whether it pertains to weight, tires, gasoline or upkeep. They do care, because they have passed the social stage, I may say, in the appreciation of the automobile. They are now on a practical day-in and day-out service basis. We believe that this movement, which is fostered and being promoted very energetically by the Society of Automotive Engineers, will be acquiesced in and adopted by the manufacturers, not because they merely desire to improve automobiles, but because they want to maintain their volume of production and build their business. There will be a very strong movement toward more efficient, more economical cars.

Better Gasoline Wanted

During the past 10 months I have visited every State in the Union except two. I have talked with thousands of automobile dealers, owners, salesmen and service-men. The producers of automobiles and the producers of fuel should realize that there is a very insistent demand on the part of the public for what it calls a better grade of gasoline. The engineers might say a more standard grade of gasoline. I do believe that the public is demanding not so much a lower price for gasoline as a more efficient kind of service from the gasoline used. We hear the demand everywhere, and I think it should be recognized.

We hear frequently now that the automobile industry is not growing, and that possibly we will not need so much fuel in the future as we have thought we would need. It is our belief that the so-called saturation-point will never be reached until every place in the civilized world is united to every other place by some unit of transportation, and that the passenger car of the future will serve as a very important part of that system. The future of the motor truck is, in my opinion, almost beyond our comprehension.

What Increased Efficiency Would Mean

The question of economy in design and operation is becoming more and more acute and widely talked about. There are 4,000,000 Fords in this Country. Assuming that every Ford owner drives his car 5000 miles a year we have a total of 20,000,000,000 miles per year. At 20 miles per gal., the consumption would be 1,000,000,000 gal. At 20 cents per gal., which is low, the total cost would be $200,000,000. Now if a saving of 10 per cent could be made by the joint efforts of the engineers building motor cars, the carbureter designers and the fuel producers, it would mean $20,000,000 to Ford owners, which would mean the sale of 40,000 more Fords, and the consumption of more gas. Naturally I take the sales point of view. All good merchandisers recognize the fact that volume at a low margin is more profitable than a smaller volume at a higher price.

The Yellow Taxicab Co. of Chicago operates 1300 cabs. It uses 350,000 gal. of "gas" per month. It is now manufacturing its own gas. At 20 cents per gallon that amounts to $840,000 per year. A saving of 1 cent per gal. would mean $42,000, or the equivalent of 210,000 miles of service.

I mention the figures relating to Fords and Ford owners, and to the Yellow Taxicab Co., because they serve as concrete illustrations of what it would mean to all of the car owners in the United States, if some small increase, some small percentage of improvement, were made in the efficiency of motor cars.

There is a very insistent demand on the part of mechanics all over the Country for better gas, as they say, or a more standard grade of gas. One engineer told me about having to take down the engine of one of the best cars built every fifteen thousand miles to repair the damage that had been done by poor gas, rotten gas as he called it.

There are 10,000,000 people in this Country using your product and our product. We are selling your product as well as our own. We have reached the conclusion that if we render better service our product will be sold more effectively; and that our volume of business and profits will be increased, if we strive with might and main to improve the character of our product.

We of the National Automobile Chamber of Commerce have great respect for your organization. You represent in your own industry about the same thing that we represent in ours. You have here today some very able men representing the Society of Automotive Engineers and various departments of the Government, and others well qualified to be of assistance to our industry and to yours in promoting research work which will help us meet this situation. The manufacturers of motor cars are sincerely anxious that the American Petroleum Institute accept this offer of cooperation. It will be fulfilled in spirit and deed. We hope that out of this gathering will come some definite expression or some definite practical effort toward the solution of the fuel problem.

H. M. CRANE

The first spokesman of the Society at the sessions was H. M. Crane, the chairman of its Research Committee. His topic was the requirements of motor-vehicle fuel. He pointed out that the growth of the automotive industry in its present form was made possible by a plentiful supply of a volatile fuel, the original 76-deg. gasoline. In spite of economic pressure for 20 years toward the use of kerosene, the public is still willing to pay twice as much for gasoline, proving its greater "utilization value" in the class of motor-car equipment that has proved practical. Engineers have learned to design equipment to use heavier and heavier fuels but there is a limit beyond which this cannot go. Some portions of the worst fuels now marketed have practically no utilization value at all in present classes of equipment and might better be thrown away. Uniformity in fuels marketed in the same territory would be an aid to economy and efficient utilization. More volatile fuels in winter than in summer, and in the colder than in the warmer parts of the Country, are desirable both for the refiner and for the user.

N. A. C. SMITH

An exposition of the volatility of motor fuel as marketed in the United States was given by N. A. C. Smith, petroleum chemist of the Bureau of Mines, which has made periodic surveys of the motor-fuel supplies marketed throughout the Country in 1915, 1917, 1919, 1920 and 1921. He summarized the results of tests of volatility to show: (*a*) periodic changes in volatility and (*b*) variations between fuels from different companies marketed simultaneously in the same territories. The end-point was taken as the criterion of volatility and it was shown that the average end-point has risen steadily from about 370 deg. fahr. in 1915 to about 445 deg. in 1920, with a slight drop in 1921. The average end-point of the least volatile 10 per cent of the fuels was compared with that of the 10 per cent most volatile fuels. The differ-

ence between these was a maximum of 110 deg. fahr. in 1919, and has been growing somewhat less, from which Mr. Smith concluded that there is a natural trend toward greater uniformity in motor fuels marketed by different companies.

F. A. HOWARD

The qualitative limitations in refining and marketing were discussed by F. A. Howard, manager of the development department of the Standard Oil Co. of New Jersey. He enumerated the possible limitations in refining of motor fuel as: (*a*) heating value, (*b*) volatility, (*c*) purity and stability and (*d*) combustion characteristics. He showed that, for practical purposes, volatility alone imposes any real limitation on fuels produced from sources at present available. The present Government-specification gasoline was referred to as two parts head, seven parts body and one part tail; while the available supply of crude includes about 35 parts tail, most of which have to be marketed in the form of other products. Marketing limitations are volatility and susceptibility to water. It is impossible to market by present methods a fuel of too low a boiling-point or one that is injured by the presence of small amounts of water. The present marketing system cannot handle different grades of fuel without adding greatly to the cost; it tends therefore to uniformity. Gasoline as a primary fuel must be produced at a minimum of labor costs, as its function is to conserve labor.

F. C. MOCK

The limitations imposed on economy by volatility changes in motor fuel were outlined by F. C. Mock, research engineer of the Stromberg Motor Devices Co. He characterized the intake system of the automobile engine as a still in which the liquid is metered continually at the intake end, the behavior of the engine depending, however, upon the amounts of vapor at the outlet end. Most of the difficulties in carburetion arise from the nature of this still system when applied to less and less volatile fuels. The engine and the carbureting system have been improved to meet the changing quality of fuels but this does not apply to cars that have been in use for several years. In particular, the high-grade cars, which do not wear out quickly, are compelled to operate much of the time with fuels for which they are not adapted. The motor fuels marketed have ranged from too volatile to operate in summer to those that could not be lighted with a match at 5 deg. fahr. While some variations may be necessary and desirable, there should be a recognized standard, and variation from it should be clearly specified as such.

C. K. FRANCIS

In the matter of the extent and causes of the present variations in the quality of motor fuel, C. K. Francis, chief chemist of Cosden & Co., took the ground that the demands of the public which the engineer attempts to meet are for speed and "pep," without much regard to how these are secured. The status of gasoline has changed in 20 years from that of an almost worthless nuisance to a product of prime importance in the petroleum output. The accepted laboratory tests for motor fuel were discussed by Mr. Francis in some detail.

Gravity is no longer considered an index of quality, since, with the advent of a wide variety of crude oils, there is no longer any definite relationship between specific gravity and any other important property of gasoline.

The tests for sulphur-content are not yet entirely satisfactory. Sulphur compounds in general must be removed to prevent corrosion and present refining processes are quite capable of accomplishing this. Better methods of test are being developed. Mr. Francis stated that free sulphur present to the extent of 0.008 per cent is deleterious and larger amounts are very bad.

The presence of unsaturated compounds is not detrimental in itself but under some conditions, not yet very well under control, these compounds may lead to the formation of gummy compounds that are very objectionable. Gasoline should be entirely free from acid and can be so produced without difficulty.

The total available energy of all gasolines as represented by their heats of combustion does not vary more than a few per cent from 20,000 B.t.u. per lb. The energy per gallon is greater for the heavier fuels.

The distillation curve representing the volatility of the gasoline is a measure of its "pep," the quality most desired by the average user; and volatility is the most important of the laboratory tests. Most gasolines are marketed today at wholesale on a volatility basis and the distillation characteristics of the product reaching the consumer are secured by blending, in which very volatile casinghead gasoline plays an important part. There is no real definition of what gasoline really is. With regard to the marketing of several different grades, Mr. Francis asked, With a more exact knowledge of the uses to which a gasoline is to be put, is it not possible to imagine that several grades of gasoline should be sold at the filling station? The present practice, at least in many places, is to put the same gasoline into a Ford that goes into a Locomobile.

Mr. Francis warned against too close specifications for gasoline. He maintained that the present Government specifications are so close as to limit the output of the smaller refiners and that the general adoption of such rigid specifications would be a hardship on them and increase the price to the public.

O. C. BERRY

With relation to the practical effects of too low volatility, O. C. Berry, chief engineer of the Wheeler-Schebler Carburetor Co., drew a distinction between the results obtainable in the use of present-day fuels under experimental conditions and those secured in practice, and pointed out the reasons for this difference. It has been impossible for the engineer to put into the hands of the public an engine that will utilize present fuels without serious difficulty and waste, and any further decrease in volatility would decrease the usefulness of the 10,000,000 vehicles now in use. The automotive engineers are making every effort to remedy this situation and it can be expected that they will find means in the near future for producing engines that will use present and even heavier fuels with entire satisfaction, but until that time the petroleum refiners are urged to make no further reduction in the volatility of commercial motor fuel.

PRESIDENT BEECROFT

Research work is necessary at this time when the attention of the world is focused on the subject of greater efficiency and economy. In the earlier days of our industries it was not a necessity; today it is obviously a necessity. I regret that the executives of the great petroleum industry of this Country and the executives of the various groups constituting the automotive industries are not meeting together to discuss a common research program.

The Society of Automotive Engineers is keenly appreciative of the spirit of cooperation manifested last year at the Washington meeting of the American Petroleum

Institute, and again this year by your invitation to us to participate extensively in the sessions now being held. We recognize that your request for cooperation has been prompted by a clear conception of the relationships that exist between you, the producers of the fuel for the internal-combustion engine, and us, the designers of the engines and vehicles that must use the fuel.

We express the sincerest hope that we shall approach nearer and nearer to the eventual goal both of us are seeking. The Society has been considering the fuel problem at its semi-annual meetings for several years and we ask that the engineers representing your industry meet with us in increasing numbers. We solicit their membership in our Society on the basis that only by the closest cooperation of the two groups of engineers will the results be accomplished that the exigencies of the time call for.

The world will use all forms of automotive apparatus if we can make them suitable in design and operation for its needs and capacities. It is not so much a question of where the market is as of adapting the vehicle and its fuel to the possible owner. We have but one aim, and it is common to our two organizations; namely, to design the vehicles and fuels to permit of purchasing, operating and maintaining the vehicles at the lowest cost. With another mutual aim we would be erecting barriers to sales, making it more difficult for the peoples of the world to own, operate and maintain our apparatus.

America has been and is the greatest world producer of petroleum products. America has been and is the greatest producing nation of automotive vehicles. Fairly reliable statistics show that while we have approximately 10,000,000 motor vehicles in this Country, there are approximately 1,000,000 in the other parts of the world. Let us not lose sight of the fact that the world is our market and that we must set our houses in order to meet it.

Early this year our Society created a research department which had its inception nearly 2 years ago in the fuel problem that we are discussing today. We are not creating a special laboratory to carry on research work, but are cooperating with Government laboratories, such as the Bureau of Standards and the Bureau of Mines, with university laboratories and with the laboratories of companies in the various automotive industries represented in the membership of the Society. We expect this research work to become one of the major activities of the Society, not second to the standardization work that we have carried on for over 10 years and that has made the great development of the automotive industry possible.

We believe that a combined research program of your industry and our Society on the internal-combustion engine fuel program is most desirable, and look forward to the time when the expense of the work now defrayed from the regular funds of your Institute and our Society, will be borne by appropriations or endowments that will place the work on the plane that the necessities of the case demand.

CHAIRMAN LUCEY

We who are in the practical end of the petroleum industry would like to take Mr. Beecroft's little speech, take out the words "automotive engineers" and simply substitute "the oil industry." The speech would apply just the same.

In my own experience in contact with engineers, I find that, contrary to the general thought expressed, they are not theoretical but intensely practical. They have no more time for the theorists than we have. We have with us a man who contributed much in the great war. He is very much interested in the subject we are discussing, having been the founder of one of the courses in connection with the study of the oil problem in a principal college in England, and having headed the petroleum industry for his Government during the war. I thought you would all like to have the opportunity of meeting Sir John Cadman.

SIR JOHN CADMAN

If there was ever evidence of the importance, the desirability and the necessity of scientific research in these great industries, it is the evidence of what we have heard this morning. When I heard the illuminating papers that were presented by men of knowledge on the subject, as a petroleum technologist my scientific conscience almost made me shout, "Atta boy!" I believe that the great internal-combustion engine industry has got to force scientific ability in the research upon this most important petroleum problem.

On the other hand, I am sensitive of the fact that the automobile engineers also realize that if they are to carry on their industry and if they are unable to force the petroleum industry into giving them those beautiful homogeneous products that they appear to desire, they must make the design of their machines so elastic that they can use efficiently without that 25-per cent loss of which we have heard, the product that the oil industry in its judgment feels that it can give.

There are a great many important problems in this connection that all of us must bear in mind. We must bring knowledge to bear upon the component parts of the product with which we are working. I do not wish to belittle in any way the great work that has already been done. The demand upon the industries has been so great that to my mind it is extraordinary that they have been able to rise to the occasion and provide the great quantity of products which you are using. But knowledge demands a further inroad into the base of this product. The realm of the physicist, the activity of the chemist and the ingenuity of the engineer are all required. What we want to know is the actual structure of the molecule that is really the primary base of this product; and when we know its structure, we have got to find out how we can handle that molecule and make it behave in the way we please. We must learn how we can add another atom of hydrogen, chiefly. That is in the realm of abstruse science; it is the real science; the subject may take years to fathom. But I believe that with the aid of the great geniuses of this Country the problem will be solved. When it is solved, the automobile engineers will be able to get exactly what they want, a homogeneous product of a molecular structure giving a possibility of bringing about combustion without any losses. Then, in truth, the activities of this great body and its sister body, the Society of Automotive Engineers, will have solved one of the great problems which they face.

O. P. KEENEY[1]

I would like to discuss very briefly the value of research work to the sales department. In a period of large stocks and diminished demand, a sales department is more than just an order-taking department, and its problems get more attention then though not more than they deserve all the time. There is a form of research that is

[1] Manager of the paraffin and lubricating sales and bulk sales departments, Tide Water Oil Co., New York City.

always important to a sales department and particularly valuable during a time of uncertain prices and difficulty in keeping the refinery storage-tanks from overflowing. It is of great importance to all phases of the industry. It has to do with the standardization of tests and testing-methods. As this research is done efficiently and uniform testing methods are evolved and put into practice, we shall see the approach of the millennium for the oil salesmen, when goods once sold will stay sold and at the price originally agreed upon; when no telegrams will be received during a falling market, such as, "Your tank-car of lubricating oil held on demurrage, not up to specifications, will unload at reduced price."

Uniform Testing-Methods

When a shipment is received and tested by a buyer, he may not use the same type of instrument or may interpret the results differently, and the chance for a most unsatisfactory dispute arises, more unsatisfactory even than the cost of demurrage or a double transportation-cost. Testing-methods and specifications are two different subjects, and I want to plead the cause of research work that will evolve and make possible the putting into actual everyday use of uniform testing-methods.

The gentlemen present representing the automotive industry are, I believe, vitally interested in this problem. They are concerned with the problem of uniformity of motor fuel. How can this be solved when the refiner and the purchaser of gasoline in describing a product can use the same general terms and each in reality mean to describe an essentially different product, because they make the same tests in different ways. I think I need not elaborate on the necessity or economy of uniformity in testing-methods. The only difficulty is in getting something done about it. After much discussion and thought, many people feel that just one thing more is necessary to have this long-contemplated ideal have the chance of becoming a reality. That is for the American Petroleum Institute to operate a research laboratory equipped to do referee testing work. This would not be an unnecessary duplication of any existing laboratory. No refinery laboratory can fulfil this function; the law prevents the Government bureaus from doing it; the commercial laboratories would be more profitable and useful if they could guarantee their work to check with this referee testing laboratory. This laboratory could also do absolutely necessary research work. The expense to the Institute need not be large, as the fees for work and for issuing certificates to commercial laboratories should bring in a good revenue. Indeed, I believe that, if necessary, various oil companies or organizations might guarantee in advance to furnish enough work for the first year to pay the running expenses.

There is an almost universal desire for uniformity in testing methods; considerable progress in that direction has been made, but further progress absolutely requires a research laboratory equipped to do referee testing. The American Petroleum Institute is the only logical organization to undertake this work.

Mechanical Standards

J. R. Stockton, vice-president of the Purchasing Agents' Association of Tulsa, Okla., made a strong plea for standardization of parts and fittings in the oil field, *on a national basis by a national organization*, stating that the American Petroleum Institute is the logical body to foster the movement. He said that the need for a broader and more comprehensive standardization had long been recognized, but that those most vitally interested have in this, as in many of their other interests, played the great American game of "passing the buck," losing hundreds of thousands of dollars as a result of this attitude. He explained that purchasing agents, in touch with both their own stocks and those of the supply companies, see this very clearly. The duplication of stocks in the hands of both the producers and the supply companies, which even a little standardization would materially cut down, is enormous. The operating companies have to pay the carrying charges on these stocks, whether they are carried in their warehouses or not. It is only natural, therefore, that there should be much interest in standardization.

A. W. AMBROSE

Discussing petroleum research, A. W. Ambrose, chief petroleum technologist of the Bureau of Mines, gave an interesting account of general and specific problems in this field. Some of the points he made were as follows:

Much research is ultra-scientific and closely associated with theoretical deductions. As a result, some people are inclined to place all research in a class that perhaps can be best described as high-brow work. This possibly accounts for a certain feeling that research work does not tie up with the business end of the industry. This is a mistake, for engineering research and investigation can in many cases be easily translated into large financial returns. Often a piece of work of a few weeks' duration will give results that can be easily measured in dollars and cents. For example, an oil company in the Mid-Continent oil fields approached the Bureau of Mines' field men at Bartlesville, Okla., on a problem of sour gasoline. In less than 1 week tests had been carried on which demonstrated that the gasoline could be made sweet by a treatment costing $0.001 per gal. The company had a production of gasoline of 250,000 gal. per month, and as a result of this 1 week's investigation it sold its gasoline for an additional 3 cents per gal., thus increasing its revenue about $7,500 per month. That is practical research.

There is of course another type of research that extends over a long period of time, but often this furnishes fundamental data that are the basis of further work. It is difficult to show that such work has a money basis but it is there just the same. The petroleum industry needs both the practical type of research concerning the immediate problems at hand and that of a more scientific nature which furnishes fundamental data.

Perhaps the most important problem today is a study of the better utilization of the fuel-oil fraction of our crude oil. Fifty-five to 60 per cent of the crude oil produced in the United States is burned directly under boilers to produce steam, and this percentage indicates the importance of the problem. It seems advisable when we have a limited supply of fuel oil that it should be utilized so as to go around as far as possible. There are many plants where the needed power can be furnished as readily by a Diesel engine as by steam turbines or other forms of steam engine. An ordinary steam-engine power-plant in which fuel oil is burned directly under boilers will have an overall efficiency of from 10 to 12 per cent. If this same fuel oil is used in an internal-combustion engine of the Diesel type, the efficiency will perhaps be as high as 33 per cent. This means that a given amount of fuel oil will yield about three times as much power. The trend at present therefore should be toward the use of Diesel-type engines.

Much oil is needed, however, for use under steam boilers and there is room for improvement in the design

of burners for handling this oil, in both steam atomizing and mechanical burners. The possibilities of such investigative work were indicated when boiler inspectors in California in the service of the United States Fuel Administration demonstrated that fuel-oil consumption of almost every plant inspected could be reduced from 5 to 25 per cent by making simple tests and repairs which involved no new purchases of expensive equipment.

Unsaturated Hydrocarbons

A most important problem today is the better utilization of motor fuels. We should appreciate that sooner or later the automobile user must face the necessity of using motor fuels that are comparatively high in unsaturated hydrocarbons. Cracking will probably become more and more general and the products of oil from oil shale also will undoubtedly be high in unsaturated hydrocarbons. The vast deposits of asphalts, heavy oils, tars, oil sands and oil shales located throughout the different parts of the United States, Canada and the South American countries will undoubtedly furnish some of our future gasoline. The possibility of the recovery of lighter oils from these sources should be investigated, for the supply is almost unlimited. The Bureau of Mines has been working on this problem for a couple of years and has demonstrated on a laboratory scale that it is possible to recover the oil from the oil sands and to even recover from the heavy asphalts light oils with a gasoline content of perhaps 20 per cent. The results of this work indicate, however, that we can expect such oils to be highly unsaturated. Investigations should be made to know which of the unsaturated hydrocarbons are harmful, whether they can be eliminated and how they can be distinguished one from another.

Lubricating Oils

Perhaps one of the most neglected branches of investigative work of the petroleum industry is the scientific study of lubrication. Most users have little idea of the proper lubricant for their special purposes. Consumers continue to use a certain lubricant for the reason that it gives a fairly satisfactory result. They are not informed, however, as to the reason some lubricants work in some cases, while they do not work in others.

A most important problem in refining engineering is the production of cylinder oils for steam and gas engines from crudes other than those of the Appalachian district. Today a large part of the cylinder stock is obtained from Appalachian crude and knowledge of how to treat other crudes is very limited. We have apparently been willing to accept this condition without studying the possibilities of the various fields.

Greater Recovery of Oil

Research problems are by no means limited to chemistry and refining, for there are real opportunities for engineering and investigative work in the production of petroleum in the fields. It has been stated that perhaps 80 per cent of the original oil is left in the sand due to the exhaustion of the gas. The manner in which gas serves as an expulsive medium was made clear by an experiment in which a steel container about 3 ft. long and 3 in. in diameter was filled with sand which was then thoroughly saturated with oil. The amount of oil introduced was known by weight and measurement. After the sand had been saturated, gas was forced into the container under a pressure of 200 lb. per sq. in. Then a valve at one end was opened and the gas allowed to escape, bringing with it perhaps 18 per cent of the oil put into the container. In other experiments the amount of oil recovered varied from 15 to 25 per cent, depending on the pressure and other conditions. After the gas had forced out 18 per cent of the oil, the container was held in a vertical position for the purpose of determining how much oil would drain out, but the capillary force exerted on the oil was so great that only a negligible quantity of oil drained from the sand. In other words, this simple experiment emphasized the fact that gas is the predominant factor in moving the oil to the well and that when the gas is gone, the production is gone. In any event it is unquestionable that large quantities of oil are left underground and whether the figure is 80 or 60 per cent, it is too large. Obviously we should start work to determine means for obtaining a greater recovery.

In certain parts of the Appalachian Fields, the practice of forcing compressed air or gas into a central well, whence it goes to adjoining wells and carries the oil with it, has caused wells to produce as much oil as they had up to the point when considered ready for abandonment. There are undoubtedly other means of effecting a greater recovery and these questions should be studied and applied before the wells are abandoned.

In connection with the prospect of there being in operation in this Country within the next few years 15,000,000 automobiles, Mr. Ambrose called attention to the fact that, although owing to the recent industrial depression, the copper industry is using 7,000,000 bbl. less gasoline per year than normal, and the ships are taking less oil from the market, nevertheless the consumption of gasoline has been greater currently than ever before. He said that the supply of shale oil is estimated conservatively at 100,000,000,000 bbl., and that Canada, Mexico and South America have extensive oil outcroppings in one form or another.

ROBERT E. WILSON

Asserting that the volatility of motor fuel, which is the property of greatest importance as regards the behavior of fuel in a manifold, is not defined by the usual distillation test, Prof. Robert E. Wilson, director of the research laboratory of applied chemistry of Massachusetts Institute of Technology, outlined the characteristics involved. His address is given substantially in full below, as it is felt that what he had to say is of such unusual importance that it should be recorded promptly. His topic was

How Can We Measure the True Volatility of Motor Fuel?

I believe that everyone here realizes, at least in a qualitative way, the importance of volatility in ease of starting, in distribution, in fuel economy and in crankcase dilution. For that reason, both the producers and the consumers have placed great emphasis upon the distillation test and upon specifications based upon that test.

It is my purpose to show that the distillation test as at present conducted, as a whole or any part thereof, is not a satisfactory measure, either of the ease of starting or of the ease of securing proper distribution by complete vaporization. Along with proper distribution comes, of course, the question of fuel economy and crankcase dilution.

I shall discuss the topic, "How can we measure the true volatility of motor fuel for the purpose for which it is to be used? and the related question, How can we draw up specifications that will insure getting what the con-

(*Concluded on page* 17)

Vol. X January, 1922 No. 1

Methods of Measuring Detonation in Engines

By Thomas Midgley, Jr.[1] and T. A. Boyd[2]

Annual Meeting Paper *Illustrated with* Diagrams

THE various methods employed to measure detonation or fuel knock in an internal-combustion engine, such as the listening indicator, temperature and bouncing-pin, are discussed and the reasons all but the last cannot be employed to give satisfactory indications of the detonation tendencies of fuels are given. The bouncing-pin method, which is a combination of the indicator developed by the author and the apparatus designed by Dr. H. C. Dickinson at the Bureau of Standards, is illustrated and described. In this method the evolution of gas from an electrolytic cell containing sulphuric acid and distilled water measures the bouncing-pin fluctuations in a given period of time. The accuracy of this method of comparison is brought out in a table.

The qualities that a standard fuel must possess are explained and the objections to a special gasoline are pointed out. The use of a combination of a non-detonating and a detonating fuel as the standard is developed and the reasons that led to the use of hexane with diethyl selenide and isopropyl nitrite for a fuel standard are mentioned.

THE detonation that occurs in the combustion of compressed mixtures of gasoline and air has interposed an effective barrier to obtaining higher thermal efficiencies from automotive engines. Because the degree of detonation, which in conformity with what is becoming general practice is the term used in this paper to designate the fuel knock, increases with compression the compression-ratio at which engines can be run on commercial gasoline is limited, and on account of this limitation the fuel economies obtained from gasoline engines have been unnecessarily low. In spite of the importance of this factor and the attention that has been devoted to it during the last few years, no accurate method has so far been presented for measuring its intensity. The purpose of this paper is to discuss the various methods that have been used for observing or measuring detonation in engines, and to describe a new and accurate method for measuring the intensity of detonation.

Three elements are of primary importance in a universal method for measuring the intensity of detonation. First, the method should embody a means for indicating the relative intensities of different detonation waves. Second, it should comprise a means of integrating the intensities of individual waves over a period of time, and of yielding a numerical value as a result, which is accurate and can be duplicated by others using the same method. Third, a standard fuel should be used as a basis of comparison, so that the results obtained can be repeated by different observers and under different conditions.

[1] M.S.A.E.—Chief engineer, fuel research section, General Motors Research Corporation, Dayton, Ohio.

[2] Research engineer, fuel section, General Motors Research Corporation, Dayton, Ohio.

TABLE 1—METHODS OF OBSERVING DETONATION

Method	Nature of Record
Listening	Descriptive phrases, spark-advance, manifold vacuum, or compression
Indicator	Direct observation or photograph
Temperature	Degrees change in temperature
Bouncing-Pin	Volume of gas evolved per minute

In Table I are listed four different methods of measuring detonation and the type of record that is possible in each case. These methods will now be discussed in the order given. The spectroscope has been used to a considerable extent by this laboratory for studying combustion in engines. It is hoped that further development will show that this instrument can be used as a very interesting and highly accurate means of comparing one combustion with another.

Listening Method

Observations of the intensity of detonation are generally made by the listening method. The observer listens to the detonation in an engine and on the basis of what he hears decides as to its intensity. The result that is obtained cannot be very accurate, and it necessarily depends largely upon the personal equation, or the temperament of the observer. The record has been something as follows: "slight pinking," "decided detonation," "severe detonation"; and, for denoting extreme conditions, such expressions as "very violent detonation," or "it can be heard across a 10-acre lot."

This method is improved by recording the spark-advance necessary to produce some critical degree of detonation that the observer believes his hearing is trained to detect accurately, or by making use of some other factor such as intake-manifold vacuum, variable-compression engines, or water-temperature readings. All of these variations of the method depend for their value upon the keenness and accuracy with which the observer can detect slight changes in the intensity of detonation.

It has been found that an observer in a car on the road and on known hills gets results that are reasonably consistent. In the dynamometer room, however, with the attendant confusion of engine noises the results of the most careful observers are erratic and inaccurate. In fact the best trained ear in our organization is barely able to detect a difference in operation between straight gasoline and gasoline with an addition of 20 per cent of kerosene. This is an error approximately four times as great as can be detected on the road. Something better than the personal hearing of the investigator is essential if small differences in the behavior of fuels are to be studied.

Indicator Method

The use of an indicator for determining the intensity of detonation is a decided improvement over the listen-

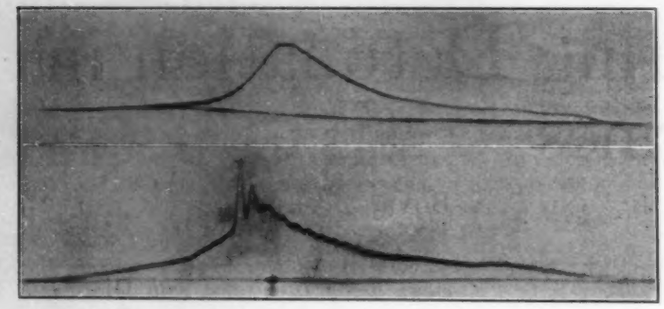

FIG. 1—INDICATOR-CARDS, THE TOP ONE SHOWING A NORMAL COMBUSTION AND THAT UNDERNEATH ONE IN WHICH DETONATION OCCURRED

ing method. We have been using such an instrument for several years. It is substantially as accurate as observation by ear on the road. In employing the indicator for this purpose it is essential that pressure-time cards be used. It is evident that fuels giving the same intensity of detonation will give indicator-cards that are alike. The accuracy with which a determination of the intensity of detonation can be made by this method depends upon the ability of the observer to compare the indicator-card of the fuel under examination with the card given by some standard fuel. Here the personal equation enters, and it is largely this factor that makes the indicator method of measuring detonation unsuitable for accurate work. In Fig. 1 (at the top) are shown indicator-cards of a normal combustion and (underneath) of a combustion in which detonation has occurred.

TEMPERATURE METHOD

The temperature method is based upon the measurement of the change in temperature incident to detonation. The use of the temperature factor for this purpose was suggested, we believe, by Doctor Winchester, of the Standard Oil Co. of New Jersey. It has been observed for some time that a general overheating of the engine apparently occurs during detonation: the excellent work done by the Bureau of Standards established this fact beyond question.

In our use of this method a thermocouple was placed in such a position that it would be quickly affected by a change in the temperature of the internal walls of the engine. The terminals of the thermocouple were connected in a circuit in which was placed a very sensitive galvanometer. This gave a striking method for determining in a qualitative way the effects of small percentages of different materials toward inducing or suppressing detonation.

But the method was not satisfactory for making quantitative measurements of these effects. The reason for this is simple. Of the temperature, as shown by the thermocouple, 150 deg. cent. (302 deg. fahr.) is attributable to the normal operation of the engine; and, in the case of a detonating combustion, there is added to this another 50 deg. or so which is attributable to the detonation. It is evident that any minor disturbance of the normal operation of the engine will affect the temperature that is due to normal operation to such an extent as to represent a large percentage of the change in temperature that would ordinarily be due to detonation; so that, unless an impracticable amount of care be taken to hold all engine conditions constant, large errors are introduced into the reading of the temperature-change that is apparently due to detonation. For this reason the temperature method was found to be unsuitable for our work, in which quantitative data were essential.

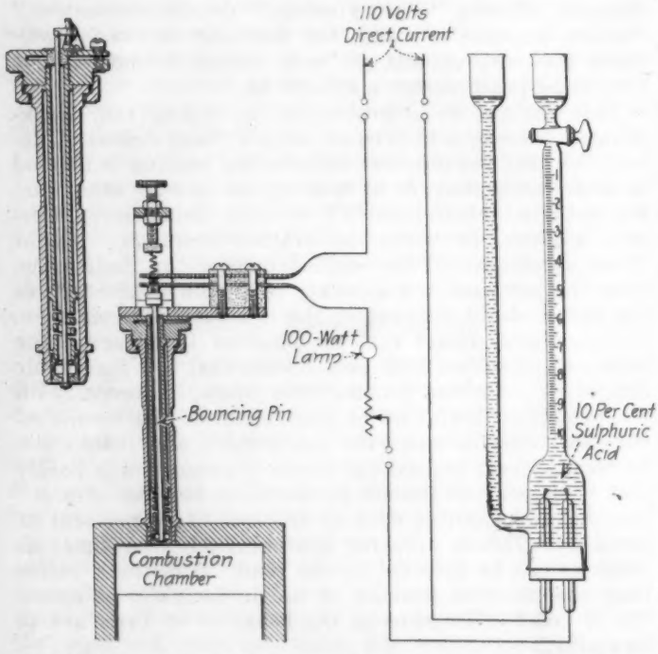

FIG. 2—AT THE UPPER LEFT THE STANDARD PRESSURE-ELEMENT OF THE MIDGLEY INDICATOR APPROXIMATELY ONE-THIRD ITS ACTUAL SIZE AND IN THE OTHER PORTION THE KNOCK-INDICATOR THAT WAS DEVELOPED FROM THIS PRESSURE-ELEMENT TO EMBODY A BOUNCING-PIN

BOUNCING-PIN METHOD

We recently had occasion to measure the influence upon combustion of small amounts of a number of materials, some of which have weak detonation-inducing properties and others are very weak suppressors of detonation. It was essential that these slight effects be measured with sufficient accuracy to permit a proper classification of the materials. We felt that at the same time it would be highly desirable to develop for measuring and recording the intensity of detonation a system that would lend itself to the commercial testing of fuels. With these things in mind, we began the development of a method to yield results of a high degree of accuracy and give numerical values that could both be obtained rapidly and duplicated by different observers. The result of this effort has been the development of an apparatus and procedure by which can be measured the effect of the addition of as little as 2 per cent of kerosene to gasoline. This is several times as accurate as measurements can be made by the listening method under similar conditions.

An essential feature of the apparatus is a modified form of Dr. H. C. Dickinson's bouncing-pin. The small drawing in the upper left corner of Fig. 2 illustrates the standard pressure-element of the Midgley Indicator that was developed by our organization some years ago. A small piston will be observed in the end of the pressure element which is designed to come flush with the head of the combustion-chamber and transmit its motion, resulting from pressure against the resisting spring, through a connecting-rod to an oscillating mirror on the top of the pressure element.

The other portion of Fig. 2 shows the knock-detector, a part of which was a development of this pressure-element to embody a bouncing-pin. The standard piston, spring and housing of the pressure element have been used, and on top of the piston has been placed a rod or bouncing-pin that rests on the piston by gravity. In order to keep the bouncing-pin free from a small but un-

desirable deposit of gum that reduced its sensitiveness to some extent, it was found of advantage to drill a number of small holes in the outer shell of the pressure element. If the superstructure or contacting device were removed and the rod allowed to have free play, it would be observed that, during normal combustion, the rod moved up and down very slightly due to its following the movement of the piston resulting from normal pressure-changes in the cylinder. But when a detonation occurred the rod would jump upward a noticeable distance and entirely clear of the piston. In fact we have seen the bouncing-pin jump as high as 1½ in. above its normal position. As a means of measuring detonation the apparatus, even in this form, is a distinct improvement over the ear of a careful and experienced observer. But, since two successive explosions are rarely exactly alike, sufficiently accurate observations could not be made by its use alone.

To secure the desired degree of accuracy it was necessary to obtain an integration of the fluctuations of the pin over a period of time. This was accomplished by arranging contact-points held in position in an electric circuit by springs in such a way as to be closed when the bouncing-pin was thrown free of the piston. An integration of the length of time the contact-points were closed was then obtained by measuring the volume of gas evolved during a 1-min. period by an electrolytic cell placed in series with the contact-points. To the cell, which contained a 10-per cent solution of sulphuric acid in distilled water, 110 volts direct current was applied through a resistance unit, this high voltage being used to reduce polarization. Platinum electrodes were used in the cell which, as is shown in the lower right corner of Fig. 2, was designed so that the evolved gas is automatically collected in a slender graduated tube at the top where its volume can be easily noted. Since a fuel under examination was always compared with another of known properties that was run immediately before and after, no correction of the volume of gas was made for temperature or for the slight liquid pressure resulting from the design of the apparatus.

In our work, which was done on a single-cylinder engine equipped with a mixing-valve, the rapid and complete changing of the fuel entering the engine when desired was facilitated by the use of a special fuel-system. This device consists of two carbureter float-bowls, arranged to be adjustable for vertical position, and two vertical glass tubes placed side by side, each connected at its bottom to one of the float-bowls. Each of the tubes was in turn connected to a three-way stopcock from which a single fuel-line ran to the mixing-valve on the engine. This arrangement permitted rapid switching from one fuel to another maintained at exactly the same level. A means was provided for the complete draining of the part of the fuel system not in use, to permit the ready substitution of different fuels.

Table 2 is given as an illustration of the accuracy with which one fuel can be compared with another by the bouncing-pin method. The results were obtained by running mixtures of kerosene and gasoline that were prepared by another person than the operator against various blends of known composition and containing the same ingredients. The composition of the fuel under examination was, of course, unknown to the operator. The average error for the six determinations given in Table 2 is 1.75 per cent.

As previously stated, this method for measuring detonation in the combustion of compressed mixtures of fuel and air was developed primarily to compare in an accurate manner the relative strength of different anti-knock materials for the suppression of detonation. Some results which were obtained in this work are shown graphically in Fig. 3. Aniline was used as the standard for the measurements, the determinations were made on an engine of 75-lb. compression, and the same kerosene was used as fuel throughout the tests.

TABLE 2—ACCURACY OF THE BOUNCING-PIN METHOD FOR COMPARING FUELS

Actual Kerosene in the Blend, per cent	Kerosene as Determined, per cent	Error, per cent
37.50	38.75	1.25
35.00	35.75	0.75
33.00	36.00	3.00
40.00	42.75	2.75
33.30	34.50	1.20
46.60	48.20	1.60

Fuel Standards for Use in Measuring Detonation

Because the intensity of detonation as it occurs in engines varies with so many factors in addition to the character of the fuel, it is essential in measuring the detonating tendency of a fuel that it be compared directly with a standard run at the same time and under the same conditions. Such factors as spark-advance, intake-manifold vacuum, or, for that matter, the compression at which a fuel detonates, are functions of the engine as well as of the fuel.

Let us consider what constitutes an ideal standard fuel for comparative purposes. It would appear that the setting aside of a limited quantity of a special gasoline, which of necessity must have an indeterminate composition, is comparable to the use of the distance from the king's nose to his thumb as the standard for the yard, instead of a bar made of bronze. Just as the length of the yard under such a condition would not be the same on two different occasions, so the composition of the re-

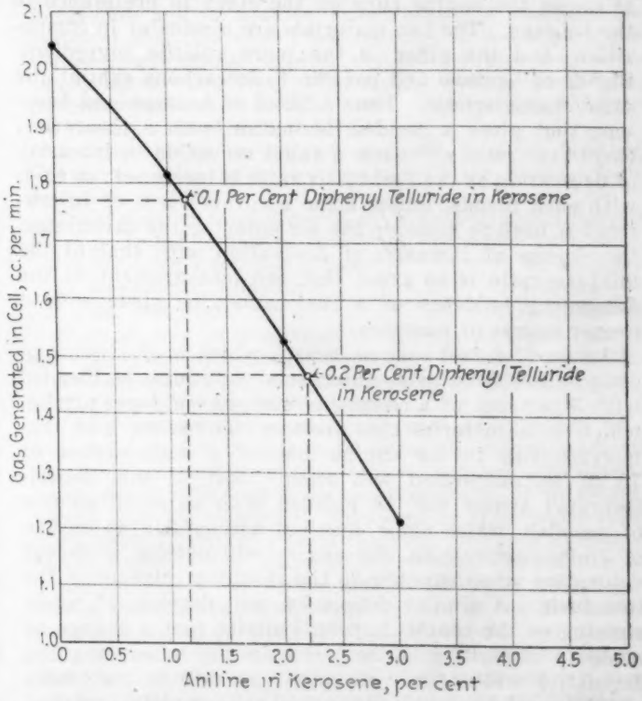

FIG. 3—RESULTS OF THE MEASUREMENT OF THE DETONATION-SUPPRESSING EFFECT OF DIPHENYL TELLURIDE BY THE BOUNCING-PIN METHOD

serve gasoline would vary from time to time unless it were sealed in an air-tight way. Furthermore, since this reserve material must be used in making tests, it must be replaced sooner or later. Any oil technologist knows that it would be practically impossible to obtain an additional supply of exactly the same material. On account of these factors a mixture of hydrocarbons of indefinite composition is unsuitable for use as a universal standard in this work. Only such fuel standards as single and pure hydrocarbons should be used. With a pure hydrocarbon as a standard fuel, additional supplies of the standard could be prepared at any time by any one having need for such a material.

For meeting these requirements it appeared that a considerable advantage would be obtained by the use of two materials, one of which would not detonate even at very high compressions, and the other give a violent detonation at ordinary compressions. The measure of the intensity of the detonation given by a fuel under examination would then be the relative percentages of these two standards required to give a blend of exactly the same detonating tendency as the fuel being measured. These materials must be such that an investigator will have little difficulty in procuring them in a pure state.

On first thought it might appear that benzene or toluene could be used as the non-detonating fuel and that sulphuric ether could be used as the detonating fuel. But blends of such materials as ether and benzene or toluene are very difficult to work with, because the intensity of detonation is extremely susceptible to slight changes in the fuel-to-air ratio. In the case of an ether-benzene fuel a rich mixture gives a very much more intense detonation than a theoretical or lean mixture. Thus a fuel of such a composition that gives no detonation with a proper mixture may detonate very violently when running on a rich mixture, all other conditions remaining the same.

This erratic operation of ether-benzene or ether-toluene blends is probably due to the fact that with rich mixtures the engine runs on the ether in preference to the benzene. The two materials are dissimilar in composition, and the ether is the more volatile ingredient. Blends of benzene and paraffin hydrocarbons exhibit the same characteristic. Thus a blend of benzene and kerosene that gives a decided detonation with a theoretical fuel-to-air ratio will show a rapid reduction in intensity of detonation as the fuel-to-air ratio is increased; so that, with such blends, unless some accurate form of instrument is used to measure the air entering the carbureter, the change of intensity of detonation with that of the mixture ratio is so great that the measurement of the detonating tendency of a fuel cannot be made with a proper degree of accuracy.

Again, if a fuel such as benzol, which is dissimilar in composition from most commercial gasolines, be blended with 5 per cent of a compound such as isopropyl nitrite, which is a material that induces detonation, and this mixture run in an engine having a compression of 75 lb. no detonation will occur. But, if this benzol-isopropyl nitrite fuel be blended with an equal volume of gasoline, which alone does not detonate in an engine of 75-lb. compression, the engine will develop a violent detonation when running on the resulting mixture of the two fuels. A similar detonation will develop, if, while running on the benzol- isopropyl nitrite fuel, a change be made to straight gasoline. But in the latter case the detonation will entirely disappear as soon as the traces of the benzol-isopropyl nitrite fuel are completely washed from the fuel-lines by the gasoline. This behavior of benzol blends is equally characteristic of other fuels, such as alcohol, that are dissimilar in composition and properties from the paraffin hydrocarbons that make up the greater percentage of our commercial gasolines.

On account of such limitations it appears that the fuels that are used for a measuring scale should be derived from either the paraffin or the naphthene series of hydrocarbons. This will insure that their characteristics when blended will not be erratic and that there will be no extreme degree of detonation during the time within which the fuels are being changed on the running engine when commercial internal-combustion engine fuels are being examined. Cyclohexane, which is the cheapest pure hydrocarbon of the naphthene series, is too expensive for such a purpose, since it costs under present conditions about $15 per gal. Only hydrocarbons of the paraffin series, therefore, appear to be available. The cost of preparing pure paraffin-hydrocarbons further limits a choice to pentane and hexane. Moreover, the low boiling-point of pentane, 97 deg. fahr., makes it unsuitable for use as a standard fuel. It appears, therefore, that hexane is the only material that is suitable for use as the basis of the system of standard fuels.

Hexane can be prepared in considerable purity by repeated fractionation of casing-head gasoline from the Pennsylvania field. It boils above 150 deg. fahr., which is considerably higher than the initial boiling-point of commercial gasolines, so that it can be used in hot weather without boiling in the fuel-lines. Because it is a member of the paraffin series of hydrocarbons its structure is very similar to that of the principal constituents of commercial motor fuels. It therefore appears to meet most nearly the rigid requirements for the basis of the standard fuels for use in the measurement of detonation as it occurs in internal-combustion engines.

But hexane does not have a sufficient tendency to detonate to be used alone for the upper end of the scale of standard fuels, nor is it sufficiently free from tendency toward detonation to be used as the fuel for the lower end of the scale. This difficulty may be overcome by taking hexane as the basis of the fuels at both extremes of the scale, and adding to one portion a detonation-inducing material to give the fuel greater tendency to detonate, and to another portion an anti-detonating material to make the fuel of lesser tendency to detonate. The standard scale would then lie between these two fuels, and the point on the scale representing the tendency of a fuel, X, to detonate would be designated by the relative percentages of the two standards required to give a fuel of the same characteristics as X from the standpoint of detonation.

A survey of the known materials that may be added to hexane for producing the above-mentioned effects indicates that isopropyl nitrite is most suitable for the detonation-inducing material, and that diethyl selenide is best suited for the detonation-suppressing material. Of the considerable number of other compounds that might appear suitable for use in this connection, none can, for one reason or another, be used for the purpose. For example, aniline cannot be used in a solution in which isopropyl nitrite is present, because of a reaction that takes place between the two materials. Isopropyl nitrite is very effective for inducing detonation, and diethyl selenide is about 10 times as effective as aniline for suppressing detonation. Both of these materials can be easily prepared, they are reasonably cheap, and both have the advantage of ready solubility in petroleum oils.

A considerable amount of work has been done in the measurement of the detonating tendencies of fuels by

the bouncing-pin method, using a 5-per cent solution of isopropyl nitrite in hexane and a ½-per cent solution of diethyl selenide in hexane, respectively, as the upper and lower ends of the standard scale. Fig. 4 shows graphically some results that were obtained. The amount of work that has been done so far in which such a fuel system was used as a standard has not been sufficient to establish the unquestionable superiority of this particular system of fuels for use under all conditions in the accurate measurement of detonation in engines. However, in the use that has been made of these standards, very good results have been obtained; and it seems certain that the ultimate standard fuels will consist of some form of detonation-inducing and anti-detonating materials dissolved in hexane.

Conclusion

An accurate observation of and a universal means for recording the intensity of detonation as it occurs in combustion can be obtained by making use of a system comprising

(1) An adaptation of Doctor Dickinson's bouncing-pin
(2) A means of obtaining an integration of the fluctuations of the pin over a definite period of time
(3) A system of standard fuels based upon a member of the paraffin series, preferably hexane, one portion blended with a detonation-inducing material and another portion blended with a detonation-suppressing material

Such a system when used by the ordinary observer will yield results that can be duplicated with accuracy from day to day, and when used by different observers will give results that are comparable.

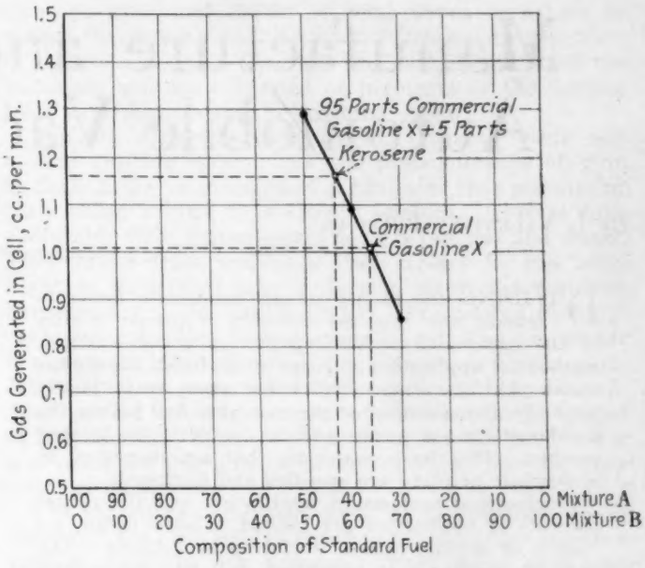

Fig. 4—Results of a Comparison by the Bouncing-Pin Method of Two Fuels with a System of Standard Fuels
Mixture A Was Composed of 95 Parts of Hexane and 5 Parts of Isopropyl Nitrite and Mixture B Was Composed of 99½ Parts of Hexane and ½ Part of Diethyl Selenide

DECEMBER COUNCIL MEETING

THE last session of the Council was held in Chicago on Dec. 5, during the week of the annual meeting of the American Petroleum Institute, in connection with which preliminary conferences were held by the Research Committee and the officers of the Society. The following members of the Council were present: President Beecroft, First Vice-President Horning, Second Vice-Presidents Bachman, Crane, Johnston and Menges, Past-President Vincent and Councilors Davis and Brush; and in addition, O. C. Berry, V. E. Clark, H. C. Dickinson, F. E. Watts, O. W. Young, and Chairman Pfeiffer and Secretary Milton of the Mid-West Section of the Society.

At the President's Dinner in the evening at the Chicago Athletic Association there were present also Herbert Chase, A. W. Ambrose and N. A. C. Smith of the Bureau of Mines, L. C. Freeman, R. O. Hendrickson, W. S. James, E. S. Jordan, Thomas Midgley, Jr., Dent Parrett, Prof. Daniel Roesch, of Armour Institute of Technology, Prof. R. E. Wilson, of Massachusetts Institute of Technology, O. B. Zimmerman, P. S. Tice and B. B. Ayers.

Fifty-four applications for individual membership and 19 for student enrollment were approved, as well as the following transfers in grade of membership: Junior to Member, T. J. Gorman; Associate to Member, Eustace B. Moore, J. D. Lannon; Foreign Member to Member, Edward C. Lange.

One hundred and twenty-four applications for membership were received during October and November as compared with 200 for the same two months of 1920. On Dec. 3 there were 5246 names on the rolls of the Society, including affiliate member representatives and enrolled students, as compared with 5230 on the same day of 1920, the slight difference being due to the fact that 662 ceased during the period to be members principally on account of non-payment of dues.

The balance sheet as of Nov. 30 showed a deficit of $1807.53 for the first 2 months of the current fiscal year. This deficit is less than that authorized by the budget that was approved by the Council in September, the decision having been that the Society should proceed this year in an active manner doing practically all of the work it had done theretofore and in addition maintaining the Research Department that was established recently; although such procedure might involve greater expenditure than income of money during this year. The income during October and November amounted to $35,525.84. The surplus funds of the Society amount to $136,817.94.

A comprehensive report was received from the Meetings Committee with regard to meetings of the Society to be held early in 1922.

The following appointments on Sectional Committees of the American Engineering Standards Committee were made:

Insulated Wires and Cables	F. W. Andrew
Aeronautic Safety Code	G. J. Mead
Ball Bearings	L. A. Cummings

A report was received from the Standards Department in the matter of the Standards Committee Division reports that it was expected would be submitted for consideration at the 1922 Annual Meeting of the Society.

Past-President Alden was designated as chairman of a committee of five that is to be organized to represent the Society in cooperative work on highway matters with Government, engineering and trade organizations. It is contemplated that the committee will also do some independent work, probably in conjunction with the Research Committee of the Society. The major consideration is the relation between the automotive vehicle and the road, this involving of course the relative cost of highway and of vehicle maintenance. It is the intention of the Council, which appreciates fully the many ramifications involved in the studies required, that the Committee shall proceed in as constructive a manner as possible on all of these matters that are submitted to it.

The next meeting of the Council will be held in New York City on Jan. 9.

Side Guide and Gripper

Manufacture and Application of Automobile Varnishes and Paints

By L. Valentine Pulsifer[1]

Annual Meeting Paper

DIVIDING the ability of an automobile finish to remain new into the elements of proper quality of the materials, engineering of application systems, methods of application and care of the finish, the author states that the responsibility for them rests jointly upon the manufacturer of the varnishes and paints, the builder of the automobile and the owner of the finished product. Five basic materials that are necessary in automobile painting are specified and discussed.

Engineering systems of application and the actual methods of application are treated in some detail, inclusive of drying, and of surfacing or rubbing. The care of the finish is important and the precautions necessary in this regard are outlined. The paper deals with the application and not the manufacture of the different varnishes and paints that are mentioned.

THIS subject is far too broad to be covered in detail in one paper. I will therefore lay greatest stress on the problems met in the proper application of automobile varnishes and paints, rather than on those involved in their manufacture, believing that it is the problem of application that interests automotive engineers chiefly. The importance of the finish of an automobile was never greater than it is to-day, for the degree of mechanical excellence already reached leaves, as the most obvious next step in development, a still further improvement in the appearance and durability of the finish. This is desirable, first, from the viewpoint of sales appeal and, second, for the strength that satisfied ownership gives to the manufacturer whose car not only continues to be good mechanically but, in addition, continues to be new in appearance.

The ability of an automobile finish to remain new is the product of four elements, the slighting of any one of which is bound to be fatal to satisfactory results. These four elements are the proper quality of the materials, engineering of the system, methods of application and care of the finish of the car. The responsibility for these four essential elements is divided among three different interested parties: the maker of the varnishes and paints, the builder of the automobile and the owner of the finished product. Unless all three do their share, the production and retention of a finish that remains new are utterly impossible. The setting forth of these four elements provides a natural division of the subject-matter of this paper into materials, systems, methods and care, to be considered in the order named.

Materials

Under the subject of the materials that go into the building of the finish of an automobile, I will cover certain points in the manufacture of varnish that will help in the understanding of the problems met in its application. There are, I presume, about 500 manufacturers of varnishes and paints in the United States. Not more than 10 per cent of these make any attempt to manufacture materials especially adapted for use in large automobile or body plants, and not much over 1 per cent exert their major efforts along these lines. "Varnish" and "paint" may be made by a man with a minimum of plant, of capital, of organization and of stocks of material. On the other hand, they may be manufactured by a company with millions invested in plants, equipment and materials both raw and finished, that has extensive laboratories, a large staff of scientific and technical experts and years of experience in a highly specialized branch of the industry.

Paint covers a range from home-made whitewash to a highly technical product such as the japan color used on an automobile. Varnish embraces everything from wall-size to wearing-body. The former is a simple solution of hardened resin in benzine and the latter is the acme of the scientific varnish-maker's art. I use the word "art" advisedly, for it literally requires art in addition to scientific skill and unlimited resources to produce in its most highly developed form the final flowing coat of varnish that completes the finish of an automobile. The varnishes that are used in automobile painting are all oleo-resinous varnishes and the various pigmented materials that are used to bring up the surface and produce the desired color, ranging from the highly elastic and impervious primer to the very inelastic and somewhat porous japan color, can be classed as varnish paints. Thus, in a broad sense, varnish forms the basic material of each coat that goes to make up the completed finish.

Oleo-resinous varnishes contain four classes of material; gum resins, fixed vegetable drying-oils, volatile vegetable or mineral oils and metallic driers. The gum resin gives to the varnish hardness and brilliancy; the fixed vegetable oil imparts elasticity and durability; the metallic driers aid the film to absorb oxygen during the drying period; and the volatile oils or thinners reduce the varnish to a workable viscosity. To understand the character of a dried film of varnish, the volatile oils, or thinners, having evaporated, can be disregarded. The driers, which have completed their function in assisting the films to absorb oxygen and become hard, can be disregarded also. The dried varnish can be considered as an alloy of gum resin and fixed vegetable oil, and its character and performance predicted by the relative proportions of these two ingredients. Varnishes that contain less oil than gum are called "short-oil" varnishes, while those containing more oil than gum are termed "long-oil" varnishes. Most rubbing varnishes fall in the short-oil category, while all finishing varnishes are long-oil varnishes.

The quickest rubbing-varnishes sometimes have as much as two parts of gum to one of oil. Three and 4-day rubbings are on the border-line between short and long-oil varnishes, some of the 4-day rubbings containing slightly more oil than gum. Finishing-varnishes range from quick gear-varnishes, containing about two parts of oil to one of gum, up to body varnishes running as high as four or five parts of oil to one of gum. Of course,

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the character of the individual materials and the processes by which they are combined, as well as the proportions in which they are "alloyed," help to determine the quality of the finished varnish. Considering materials of similar quality, the short-oil varnishes are quick-setting, fast and hard-drying, inelastic and, if exposed to the weather or even to extreme changes of temperature without the protection of a long-oil finishing varnish, will soon crack and perish. On the other hand, the long-oil varnishes work freely, flow smoothly, set slowly, dry and harden gradually and possess a high degree of elasticity. The higher the percentage of oil in their composition, the greater is their degree of elasticity and durability. They do not, of course, dry hard enough or fast enough for use in the rubbing coats, but they possess the durability necessary to afford the final protection for the whole paint structure.

The japan drier or grinding japan used in the japan colors and some of the other automobile undercoats, is really either a long or a short-oil varnish in which is incorporated a very high percentage of metallic drier. This causes the film to dry with much greater rapidity than would be the case with a normal varnish of the same gum-oil ratio and, at the same time, reduces the elasticity very greatly.

In the production of high-grade varnishes extreme care is necessary in the selection and testing of all the raw materials; in the aging, refining, bleaching and heat-treating of the oils and in the melting of the gums and their combination with the oils. Careful testing of the base, or primary, varnishes, their proper storage and selection for the blending or mixing process in the formation of the secondary or finished varnishes and, finally, the rigid check-testing against standards of each tank of the finished product, form an essential part in the production of reliable material. A full description of each step and process, from the time of arrival of the raw material at the plant until it goes out a year or so later as the finished article, would be too lengthy, and I will therefore proceed with the description of the various types of material used in building up the automobile finish from the foundation to the final coat.

Basic Materials

Five basic materials are used in automobile painting; those for priming, surfacing, coloring, rubbing and finishing. Each of these materials performs a distinct and different function and all are necessary links in the completed chain.

The primer forms the bond between the surface to be painted and the subsequent coats of material. It is the foundation of the whole structure. It must be of suitable nature to perform its duties properly and be applied over a surface properly prepared to receive it. There is no failure worse than that due to an improper primer, a primer that is improperly applied or one applied on a surface not in condition to receive it.

The surfacing materials are used for the purpose of building up a smooth surface on which to apply the color, rubbing and finishing-coats. There are two types: those surfaced by sandpapering and those surfaced by rubbing-down with block pumice or rubbing-stone and water. These latter are tougher and more dense and, although they require more time and labor, naturally give the most complete and most durable results.

Coloring materials include the so-called ground colors, japan colors, flat colors or body colors. They form a dense opaque ground on which to apply the subsequent rubbing-coats. They are extremely rapid in drying, show no gloss and should be semi-porous in nature to permit the varnish of the first rubbing-coat to penetrate to a certain extent. They are the least elastic of all the materials and are composed of pigments of the desired color carefully ground in grinding japan.

Rubbing materials comprise all types of clear and colored rubbing-varnish and the preponderance of gum in their make-up gives them a hardness that permits of their being rubbed to a smooth surface. This is done preferably with pumice-stone flour, a felt pad and water. They range from materials that air-dry to rub overnight to those that take 4 days to reach the requisite hardness for proper rubbing-down. The colored rubbing-varnishes are either factory-made by grinding the proper dry pigment into the varnish, or shop-made by the careful addition of japan color to the clear rubbing-varnish. The type of rubbing-varnish selected should be gaged by the character of the work to be turned out, the slower and more durable grades being indicated for the finer types of finish.

The finishing-varnishes used in automobile work represent the most highly developed type of oleo-resinous varnish used for any purpose. They must work and flow faultlessly, dry within a reasonable time, present a surface of mirrorlike smoothness and possess adequate toughness and elasticity to insure long life. Hardening to a final thickness of less than 0.001 in., they must protect the whole paint and varnish structure against all the elements and only too often against the abuse or neglect of a careless or ignorant owner. They are long-oil varnishes in the truest sense, and range in grade from those suitable for quick repair-work, drying to handle overnight, to the best body varnishes that require several days under normal air-drying conditions to harden sufficiently for use.

Body varnishes should be chosen for their paleness of color, freedom and safety of working, speed and perfection of flowing, time of drying and hardening in relation to durability, fullness of body and brilliancy of finish. A different type of finishing-varnish should be chosen for the hood, fenders and wheels from that used on the body, for one is needed that is more resistant to the action of mud, water, oil, grease and soap, than is required on the body. A varnish of this type does not possess the freedom of working and flowing of the finest grades of body varnish but, fortunately, the surfaces to be finished are much smaller and working qualities can be sacrificed safely to obtain greater body, toughness and resistance.

The finishing-varnish is to the paint beneath what the armorplate belt is to the vitals of the battleship and the life of the whole structure depends on its quality. It must be of the best and, even then, it cannot perform its duties successfully if placed over poor undercoats improperly applied, or over a system of painting improperly engineered.

Engineering Systems of Application

This consideration of the five basic materials appearing in a complete system of automobile painting brings us to the matter of their proper combination into the finished structure. The laying-out of an automobile painting system is an engineering problem of no less magnitude than the design of a steel bridge and, in many ways, is more complex. The various materials perform different functions exactly as do the foundations, anchorages, columns, girders and trusses of a bridge. They must bear proper relationship to each other and to the completed structure as do the various bridge members;

each must be designed and proportioned properly in relation to all the others to produce a perfect result.

The simplest possible system would consist of one coat each of primer, surfacer, color, color varnish and finishing varnish. Over a perfectly smooth, flat, metal surface, such a system would give good results as to both appearance and durability if the materials used were of the best. Under the actual conditions of automobile painting, at least double the number of coats noted above usually will be found necessary to produce a finish of good appearance and durability. In this connection it should be noted that it is just as bad practice to pile on unnecessary coats as it is to leave off materials that are necessary to the system. Just enough coats should be specified to produce the desired degree of fullness of finish. Proper shop facilities must be provided, a full time schedule allotted and an adequate degree of skill afforded in the personnel of the painting department to insure intelligent application. It is well to remember that the paint-shop and the trim-shop schedules should be interlocked wherever possible to provide *extra* days for the drying and hardening of rubbing-coats and, in this manner, added insurance of satisfactory results obtained without sacrifice of time.

In laying out the system for a given job it cannot be over-emphasized that the five basic materials must be chosen not only for their individual merit but for their ability to pull together. To obtain the proper correlation of the various coats the elasticity of the succeeding materials should be gradually *decreased* from the primer to the flat color and then gradually *increased* up to the finishing-varnish. This result is obtained by using an elastic primer. Next, a coat intermediate in elasticity between the primer and the surfacer is used; it is the so-called half-and-half or elastic roughstuff. Then the surfacer itself, possessing less elasticity, is applied, and next the flat color possessing practically no elasticity. This should be followed by gradually increasing the elasticity of the rubbing-coats produced by making each succeeding coat lower in japan color or pigment content and, finally, capping the whole with a finishing-varnish possessing the greatest degree of elasticity possible.

Methods of Application

The four methods of applying the various materials to the automobile surfaces are those of dipping, spraying, flow-coating and brushing. Dipping is used principally for the application of black baking-japans on hoods, fenders, splash-guards and small metal parts. When used in connection with endless-chain baking-equipment and a high-grade of black japan, this method affords a combination of low operating cost with a durability of finish that cannot be equalled for quantity-production work; it is used with success even on small open bodies when a black baked-finish is standard.

The now highly developed air-brush or air-gun affords perhaps the best method yet discovered for the application of the primer, surfacer and flat-color coats. It does away with troublesome brush-marks in the surfacer and flat-color coats and, in the hands of a skilled operator, gives a uniformity of thickness unexcelled by the most careful brushing. Care should be exercised in spraying to use the materials at just the proper degree of viscosity, and the operator should be cautioned especially against applying too thick a coat. This method effects a saving in time and labor that more than offsets the use of somewhat more material than in the case of brush application.

Flow-coating is a method of applying rubbing and finishing-varnish that was first tried on a very small car and now is in use in a number of large plants producing cars of the higher grades. In flow-coating, the body to be coated is mounted over a trough-like table and the varnish is applied through a flattened nozzle attached to a hose. This hose in turn is connected to a circulating pump and small reservoir of varnish. The varnish is flowed on the panels in great excess, drips off the panels into the troughs and is led back through a strainer to the reservoir from which it was originally pumped. Flow-coating possesses both good and bad points. From the viewpoint of speed of production, cheapness of operation and cleanness of finish it has great merit, but from the standpoint of the fullness and durability of the finish its use is not so successful. In the case of the rubbing-coats the tendency of short-oil varnishes to "silk," to show vertical satinlike streaks when flowed-on, more than offsets the gain made by the elimination of brushmarks. I have seen cases where this vertical silk in the flowed-on color-varnish coats was so pronounced that it could not be rubbed out without danger of cutting through to the coat underneath and, of course, this vertical silk showed through in the finishing-varnish. Also, the fact that rubbing-varnishes set or stiffen-up much more rapidly than long-oil varnishes tends to cause too wide a variation in the thickness of the film between the top and bottom of a panel. Rubbing-varnish, when flow-coated, tends to form too heavy a "fat edge," especially around door panels, to harden through properly, and this fat edge, containing semi-hardened rubbing-varnish, often wrinkles when it is softened by the turpentine of the finishing-varnish. If flow-coating is to be used for the rubbing-coats, the objectionable features that have been mentioned can be minimized by using the freest-flowing rubbing-varnishes obtainable, and their use as color varnishes in fairly thin body. For fine work the brushing of the rubbing-coats is the best practice.

The flow-coating of finishing-varnish results in a thinner residual film than is produced by the proper brushing-on of the same varnish, and this reduces both the fullness and the durability of the finish. The reason for this is apparent when it is remembered that in brushing a large panel a finisher will work over it fully 5 min. and, as something like half the turpentine content of the varnish evaporates in the first 5 min. after it is spread, it can be seen that the finisher, on his last time over the panel, is working and keeping in place a varnish of far greater viscosity than he originally applied. The average high-grade body-varnish contains about 65 per cent by weight of non-volatile material, and it will be seen that, when the finisher is through brushing it, the non-volatile content has run up to over 80 per cent. On the other hand, in the case of the flow-coat the body is being flushed with a great excess of varnish of the original viscosity until it leaves the hands of the operator, and the resulting film is consequently considerably thinner. On samples of varnish examined after a day's run in a flow-coat machine the increase in non-volatile content was only 2 or 3 per cent.

The fullness of a flow-coated finishing-varnish can be improved by extreme care in the application and rubbing of the rubbing-coats, but this solution is hardly possible where piecework prevails, for by extreme care is meant *extreme care!* The sacrifice of durability by flow-coating the finishing coat may possibly equal 20 per cent and this, unfortunately, cannot be obviated by the use of finishing-varnishes of much greater viscosity or higher non-volatile content, on account of flowing

difficulties around door-handles, wind-shield supports and moldings. Close cooperation between the automobile engineer, the foreman of the paint-shop and the chemical engineer of the varnish manufacturer will no doubt overcome in time the present objections to flow-coating on high-grade work. A so-called solution has been reached in some cases by the substitution of a finishing-varnish much shorter in oil, which, by virtue of its greater gum-content, shows a filling-up quality not possessed by a varnish long enough in oil to furnish the proper degree of durability. Such a solution will result in the sacrifice of 50 to 75 per cent of the ultimate durability of the finish, and would not be possible if proper cooperation existed between those responsible for the production of the finish.

The time-honored method of brushing, in applying all paint and varnish coats, is now restricted to use on the last two basic materials of the system, the rubbing and the finishing-coats. For these two materials application by a skilful brush-hand still represents the best practice and is in almost universal use where fine finishing is done.

Drying and Surfacing

Two other subjects come under methods of application; drying and surfacing or rubbing. The former is divided into air-drying, forced drying and baking. If time and space were no object, there would be no choice in final results between proper air-drying and proper forced-drying; but both time and space are highly important in modern quantity-production and forced drying reigns in all uptodate plants. In general, the degree of heat used should decrease with each succeeding type of material, the air used should have the requisite moisture-content to give the proper drying-rate, the heat should be applied gradually and adequate time should be allowed for the job to cool before beginning the next operation.

It is not the function of this paper to give details as to temperatures or hours required for each type of material. The rules given are general in their application. Forced drying is of little value in the final hardening of a long-oil body-varnish; the use of a temperature of much more than 85 or 90 deg. fahr. in the drying of such material merely results in a finish of thinner appearance. The main requirement in the proper drying and hardening of the best grades of finishing-varnish is a maintained temperature of at least 75 deg. fahr., without excessive humidity, and with an adequate supply of oxygen introduced by suitable ventilation. In the modern finishing-room and "dark-room" the use of an adequate air-conditioning equipment is highly desirable, especially for the assurance it gives of proper drying and hardening during humid or muggy weather. By adequate air-conditioning is meant the facility for reducing humidity as well as increasing it.

What has been said applies to the air-drying of all paint and varnish coats where air-drying is used. When forced drying is used, too much heat, heat too rapidly applied or too little moisture-content for the amount of heat used will result in "case-hardening" or surface-drying rather than proper hardening throughout. This causes a sunken-in appearance of the finish and frequently results in a premature breakdown of the whole paint structure under exposure. Like many other operations, it is erring on the safe side to go too slowly with forced drying rather than too fast.

The term "baking," when properly applied, refers to temperature-ranges above 300 deg. fahr. and to materials that harden more by heat than by oxidation. True baking is applied exclusively to blacks and, except in the case of a few small cars of very large production, is used only on hoods, fenders and the like. True baking materials cannot be used for air-drying, no matter how long a time schedule is allowable, for they would never air-dry to proper hardness.

The operations that apply to the surfacing and rubbing materials have much to do with both the appearance and the durability of the finish; more than they are sometimes given credit for. Surfaces are either sandpapered or rubbed with block rubbing-stone and water as previously described. Sanding surfaces should never be rubbed along with the use of water, because they are too porous, and the roughstuff type must be rubbed with rubbing-stone and water because they are too tough to be sandpapered.

The three methods in use for the rubbing-coats are those of dry-oil sanding, wet-oil sanding, and rubbing down with pumice-stone flour, a felt pad and water. Of these three, the last is the best practice when both appearance and durability are prime considerations. The dry-oil sanding, using sandpaper dipped in linseed oil and allowed to dry, sacrifices something in the smoothness of the finish, although it probably does not impair the durability. The wet-oil sanding, using sandpaper dipped in a mixture of linseed oil and gasoline, undoubtedly saves time and labor, but it causes a softening of the rubbing-varnish that is detrimental to the durability of the finish; this is especially true when the first coat or two of the color-varnish is wet-oil sanded and the final coat is water-rubbed.

As the rubbing with water tends to harden the coat instead of softening it, as is the case with the wet-oil sanding, this places the hardest of the rubbing-coats on top and results without question in the speeding-up of the breakdown of the finish. The use of the wet-oil sanding cannot be considered good engineering practice where the quality of the finish is the first consideration. The use of the dry-oil sanding, a substitute for the old mossing-off with curled hair, is allowable on the first coat at least of the color-varnish, although a water-rub on all coats is undoubtedly preferable where the sheer quality of the results is to be considered. This rather sketchy treatment of the methods of application is intended to be suggestive rather than informative, and yet to point out some of the possible pitfalls that high-speed production methods sometimes introduce.

Care of the Finish

This brings us to the fourth and final element in the production and retention of a satisfactory automobile finish. We will take it for granted that the varnish manufacturer has made and the automobile builder chosen the finest materials it is possible to produce, and that these materials have been applied pursuant to a scientifically sound system according to the best methods. It then rests with the car owner to do his share by treating the finish of his automobile as carefully as he would any other fine thing that he wishes to preserve.

Many car owners fail to realize that in their hands lies the matter of their cars looking as well months after they have been purchased as they did when they left the factory's finishing-room. If the owner allows caked mud to remain on the car, it may leave a spot that cannot be removed. A careful washing with clean cold water before the mud dries will avoid such spotting. Varnish will not withstand the dusting or rubbing of mud off of it, nor will its high luster survive if dust, grit and mud are driven into its surface by the water blast of a high-

pressure hose. Improper soaps, or good soaps improperly used, are a source of premature destruction of the finish, and it is dangerous to use body-polishes or so-called dry-washes and cleaners. These result in the scratching, abrading and sometimes softening of the finishing-varnish, all of which tends to shorten its life. Polishes containing wax cause trouble in the drying and decrease the durability of the new coats when a car is refinished. Many owners appear to assume that a varnish can last forever and, consequently, fail to have their cars re-varnished before the deterioration of the finish has gone so far that the undercoats are cracked and checked and a complete repainting of the car is necessary to give the car a good appearance.

All the above-mentioned difficulties can be avoided or at least minimized by instructing the owner, in the first place, what the finish of the car is and, in the second place, how to care for it properly in both upkeep and renewal. A good-looking car on the road is the product of the combined efforts of the varnish maker, the automobile builder and the car owner; and a credit and a lasting satisfaction to all three.

ENGINEERS AS MANAGERS

IN an address before the Founder Societies, Philip Cabot condemned the engineer as a manager, stating that the discipline of his professional career has curbed his enthusiasm and caused him to add 15 to 25 per cent as a factor of safety to what is indicated by his painstaking calculations. Mr. Cabot said in part

> Many reasons are assigned for the collapse of the railroads, and as in the case of all other human beings, there is doubtless no one cause. But it is very striking to note the change in type of the men who now lead the great railroad systems as compared with the men who led them when they were successful. In the earlier days our great railroad leaders were primarily traffic men; men whose vision naturally focussed upon the market, who saw the thing to be done and found some way to do it. Now the leaders of our great railroad systems are all operating men; in other words, essentially men of engineering training and the scientific type.
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> It is doubtless true that whatever the ability of these men might have been, success has been made impossible by the systems of regulation under which they have been placed. Holding the ignominious position of responsibility without power, it is no wonder if they have failed in successful leadership. But it is undeniable that they have failed conspicuously. The huge army that these men command, far from being inspired by the enthusiasm and loyalty that are essential to success, is admittedly upon the verge of mutiny.
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> In all great operations, new or old, the leading dominating spirit must be that of the idealist, the promoter, the great salesman, rather than the student or man of science. Such an attitude of mind is very difficult for the typical engineer on account of his temperament and his training. His natural position is that of the hand that executes rather than the mind that conceives. Leadership is not native to him, his enthusiasms have been put under stern control; locked up so that they cannot warp his judgment, they cannot easily be released to inspire others. In fact, they are often atrophied.
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> I do not say, nor do I believe, that it is impossible for an engineer to be a great leader and manager of industry. All that I can maintain is that his natural handicap is increased by our present methods of training to such an extent as to make him an unpromising candidate for promotion to such positions, and I say this with full knowledge of the fact that his selection to fill them has become increasingly common of late years especially in public-service corporations.
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> Stockholders are in practice a flock of sheep incapable of concerted intelligent action but eager to follow any leader, so that the task of selecting corporation managements falls upon the banker, or financial godfather of the enterprise. Such men, cautious by nature, and made doubly so by experience, yearn for a sure thing and welcome the engineer with his mathematical accuracy. Your engineer at least will not exceed his estimates, will tell in advance what he will do and do it, while your most visionary promoter must forever be watched and guided. With an engineer at the wheel the company will run itself and the banker-director can sleep in peace. But there is apt to be a rude awakening when he discovers that the business has gradually evaporated, wages have shown a disconcerting tendency to eat up profits and customers are becoming surly.
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> In this case, as in all others, the search for the sure thing fails; temporary peace is purchased at the cost of the ultimate failure and the practice must be abandoned. The bankers must select men of enthusiasm, courage and vision and put over them boards of directors who are capable and willing to direct. Your dreamer without direction will wreck you faster and more certainly than your man of science. But with adequate direction and control he is your safest man; and if our engineers are to occupy such positions with success their education and training must be profoundly modified.

There is enough probable truth in Mr. Cabot's statements to make them misleading. What he deplores is the passing of the stage in the development of the Nation when conditions favored the success of the promoter type of men. There is no longer so much opportunity for the promoter who lacks technical knowledge and ability. Any large success requires both vision and sane direction based on technical knowledge. The quality of vision is not restricted to any one type of man. Success is as likely to come under the management of a leader who has technical ability upon which to base sound judgments, and the courage to proceed, as under the management of men of the type for which Mr. Cabot pleads so interestingly.

CHICAGO FUEL MEETING

(*Concluded from page 6*)

sumer demands and yet place a minimum of restrictions upon the refiner or any one else who can add a drop to our bucket of motor fuel?

I want to say a few words with regard to specifications. Specifications have often been held up as one of the greatest obstacles to progress; indeed it has been true too often that specifications have merely taken the place of age-long prejudice and time-honored practice, to prevent *any* change, however desirable it might be to both consumer and producer.

If we analyze these cases, however, it becomes evident that the real source of difficulty is that we have not specified those properties that we really needed, but instead have tried to fix some non-essential property or some superficial indication of the desired property that happened to be more easily measured.

On the other hand, if we have specifications and tests that measure actually what we need and give them a reasonable measure of flexibility so that they may change with changing conditions, a specification becomes an *aid* to progress.

It is therefore extremely important to get satisfactory methods of tests. The volatility of motor fuel affects two entirely different things: First, the ease of starting, which is mainly controlled by the *lower* end of the distillation curve; and, second, the ease of distribution or the possibility of complete vaporization, which also determines economy and dilution. These are two separate properties and we need two separate tests for them, but *no more*.

Take first the question of what constitutes a measure of the relative ease of complete vaporization of two fuels as affecting distribution, etc. We can get some sort of an approximation to perfect distribution, even with liquid drops still present, by a proper design of manifold, but the only thing that will really distribute properly is a completely vaporized fuel. The most successful attempts to accomplish that have resulted in heating the airstream to a very considerable extent.

A measure of the comparative value of fuels for this purpose would therefore be the temperature to which the airstream would have to be heated to make possible complete vaporization. The question at once arises, Why is this point not the end-point of the fuel? or Why does it not bear some direct relation to the end-point?

There are two entirely different ways in which vaporization can take place, one of which occurs in a distillation flask and the other under the conditions that prevail in the manifold. In the one case, consider that we have a distillation flask nearly full of a fuel, and are continually distilling it off. Suppose that the fuel consists of very volatile, less volatile and still less volatile fractions, which I will designate as *A*, *B* and *C*. *A* is the first thing that comes off. It fills the vapor space, and more *A* comes off and keeps shoving it out of the way. Then *B* begins to come off, also forcing *A* out of the flask, and before half of *B* is gone, *A* will be almost completely scrubbed out of the flask. Similarly, before half of *C* is gone, *B* will be practically completely scrubbed out of the flask. The end-point we get, that is, the temperature necessary to vaporize the last drop of the fuel, will depend almost wholly upon the least volatile materials in the fuel, since the composition of the boiling liquid depends upon that of the vapor in contact with it.

There is, however, another way we can carry out this vaporization. We can have a tall gas-holder filled with air, with a fan to get circulation, and just a little pot of motor fuel in the bottom. We can start to vaporize *A*, *B* and *C* into this space, and keep stirring the air around to have equilibrium in there. We are now vaporizing this liquid into a space that *already contains* all that has thus far been vaporized. Some *A* is therefore continually redissolving in the liquid to make up for that which is evaporating and when we get down to the last drop it does not consist merely of *C*, the last volatile portion, but there is a considerable amount of *B* and some of *A*

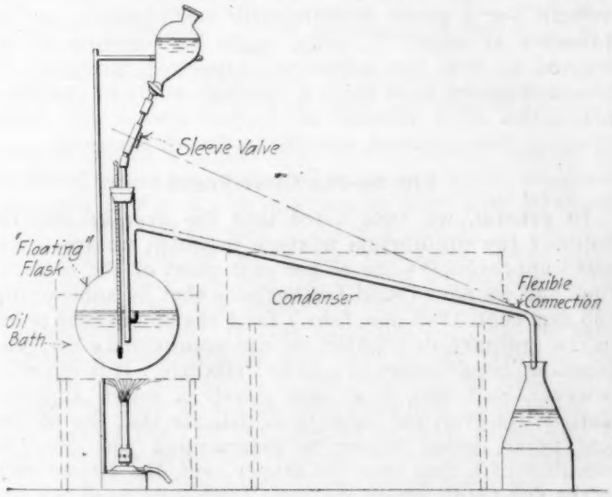

FIG. 1—APPARATUS FOR PREPARATION OF EQUILIBRIUM SOLUTION ARRANGED FOR AUTOMATIC REGULATION

still present. The composition of the last drop is therefore a sort of integration of the whole distillation-curve from the standpoint of completeness of vaporization into an airstream. It is much more volatile than what we got in the ordinary distillation test because it contains a considerable portion of these lighter ends. It does, however, contain a greater proportion of the heavier ends, its average boiling-point corresponding roughly to the 85-per cent point of the original fuel.

Now this last method of evaporation is essentially that which takes place in the manifold of an engine, because the last drop of the fuel is evaporating into an airstream already containing the lighter constituents. A method that we have developed for securing a sample of this equilibrium mixture corresponding to the last of the fuel to evaporate in a manifold has been described in detail[2]; so I will merely summarize the operation, which is carried out in a flask such as that shown in Fig. 1. The upper reservoir is kept full and the flask filled half-full with the fuel to be tested. The temperature of the oil-bath is then raised until some of the fuel begins to distill off. The most volatile portions of the fuel in the flask are the first to be boiled-off and condensed. We keep running in fresh fuel containing both high and low ends to keep this level constant, as indicated by the hook

[2] See THE JOURNAL, November, 1921, p. 313.

gage. The boiling-point gradually rises because equal amounts of high and low are coming in and we are distilling off more of the low. Finally, after ½ or ¾ hr. of this continuous process, the boiling-point of the liquid in the flask becomes constant, which shows that the composition of this liquid is no longer changing. Since neither the amount nor the composition of the fuel is changing, the input of fuel must be the same as the output. In other words, we are putting in the original gasoline and taking out the vapor of completely vaporized gasoline. Furthermore, this liquid in the flask is in equilibrium with the completely vaporized gasoline, and therefore has the same composition as the first drop to condense, or the last drop to be vaporized, under the conditions prevailing in the manifold.

By this method, however, we have been able to get, not a single drop, but a whole flask full of gasoline which has integrated the distillation-curve of the fuel exactly as it is done in service. We can take samples of this "equilibrium mixture" and determine its vapor pressure and the temperature at which it would be completely volatile for a given mixture-ratio and pressure, or the pressure at which it would begin to condense if we started to cool the completely vaporized mixture. In this manner we have made a thorough study of the characteristics of a number of typical present-day fuels, ranging from aviation gasoline to Socony kerosene.

The 85-Per Cent Point

In general, we have noted that the average boiling-point of the equilibrium mixture in which we are interested approximates the 85-per cent point of the original fuel, and we have found furthermore that by subtracting 135 deg. cent. (243 deg. fahr.) from the 85-per cent point in the ordinary distillation we can approximate the condensation temperature of a 12 to 1 mixture. It is obvious, however, that this is at best merely a rough approximation; its principal value is to indicate that the 85-per cent point comes nearer to determining the effective volatility of a fuel than the 50-per cent, the 90-per cent or the end point, which are more frequently used for the purpose.

While the preparation of the equilibrium mixture is a simple proposition, the measurement of its vapor pressure is rather difficult and not at all well adapted to routine tests, although it can be carried out in any laboratory if sufficient care is taken. We have therefore tried to find out whether it might not be possible to get a fairly good approximation by subtracting a constant amount from the final constant-temperature obtained in preparing the equilibrium mixture. A little consideration of the thermodynamics involved will show that this could not be true for fuels containing the higher-boiling alcohols or for any fuel differing greatly in composition, although for paraffins and naphthenes not excessively unsaturated it should hold fairly well. Actually by subtracting 120 deg. cent. (216 deg. fahr.) from this equilibrium boiling-point it is possible to obtain the condensation temperature of five or six fuels tested, with an average deviation of only 3 deg. cent. (5.4 deg. fahr.) as compared with an average deviation over twice as great for the 85-per cent point method. The single exception to this rule in the six fuels tested was in the case of Red Crown kerosene whose Baumé compared with its boiling-point showed conclusively that it was far outside the range of composition of ordinary gasolines or paraffin kerosenes. For all ordinary motor fuels it would appear, at least until further evidence is secured, that this approximation is entirely satisfactory.

To make the method of preparing the equilibrium solution somewhat simpler, the maintenance of the constant level in the distillation flask shown in Fig. 1 has been made automatic by the use of the sleeve-valve and the floating flask as shown. It is merely necessary to keep the temperature of the oil-bath roughly 40 deg. cent. (72 deg. fahr.) above that of the liquid boiling in the flask, and to use a small, well-ground sleeve-valve that feeds in liquid when the flask rises slightly and shuts it off as soon as the flask begins to sink. The temperature and level of the oil bath must be kept reasonably constant to enable this to be done. For ordinary work, however, it is easy enough to control the level in the flask by operating the stop-cock by hand.

By this means we have apparently a simple and reasonably accurate method of determining the "condensation temperature," or what we may call the "effective end-point" of the fuel. Complete vapor-pressure measurements must, however, be made on several more fuels from different sources before the accuracy of the recommended approximation can be considered as established.

Ease of Starting

Let us consider next the volatility of the fuel so far as it affects the ease of starting. The effective volatility for this purpose is different from that which we have been discussing, since we require only *partial* evaporation of the fuel to get a mixture rich enough to ignite, and this volatility depends primarily upon the initial part of the curve, although not on the initial point nor on any single point on the curve.

To illustrate how far in error we may go by taking the initial boiling-point of a fuel as a measure of its ease of starting, consider three fuels which have almost identically the same boiling-point, alcohol, benzol and a hypothetical paraffin hydrocarbon with a boiling-point of 80 deg. cent. (176 deg. fahr.) whose properties are determined by interpolation on the assumption that it is 60 per cent normal hexane having a boiling point of 68 deg. cent. (154 deg. fahr.) and 40 per cent normal heptane with a boiling-point of 98 deg. cent. (208 deg. fahr.). It is generally realized that it is much harder to start on alcohol, but the causes therefor have never, apparently, been analyzed in detail.

To represent the situation clearly, Fig. 2 has been drawn. In this curve the logarithm of the vapor-pressure of the three fuels has been plotted against the reciprocal of the absolute temperature, but the numbered coordinates show the vapor-pressure in millimeters of mercury and the temperature in degrees centrigrade and fahrenheit corresponding thereto. The advantage of plotting in this way is that the vapor-pressure curve is substantially a straight line and its slope is determined by the heat of vaporization of the fuel.

It will be noted that the three fuels have a vapor-pressure of 760 mm. (29.92 in.) at very nearly the same temperature; in other words, they have the same boiling-point. For the purpose in hand, however, we are interested in much lower vapor-pressures corresponding to the leanest mixture which will ignite, which is in the neighborhood of 11 mm. (0.43 in.) for the paraffin hydrocarbon. The rate of change of vapor-pressure with temperature therefore becomes an important item in determining the relative ease of starting, and it will be noted that the vapor-pressure of alcohol drops off much more rapidly than that of benzol or the paraffin hydrocarbon; in other words, while all the fuels require about the same temperature to give a vapor pressure of 760 mm. (29.92 in.), the alcohol must be 15 deg. cent. (27 deg.

fahr.) warmer than the paraffin hydrocarbon to give a vapor pressure of 11 mm. (0.43 in.).

Ignition

The second difference between the fuels is in the richness of the mixture necessary to make ignition possible. The paraffin hydrocarbon and benzol are very similar in this respect, but the molecular weight of alcohol is so much lower than that of the other fuels that the required vapor-pressure is nearly three times as great, as shown by the *vertical position* of the horizontal lines for each fuel in Fig. 2. This is again unfavorable to the alcohol as far as ease of starting is concerned.

Heat Required for Evaporation

The third difference between the fuels is in the amount of heat that they require for evaporation. If a fuel and a stream of air are brought separately to the same temperature and then mixed, there will be a very marked cooling, due to the absorption of the heat of vaporization as the fuel evaporates into the airstream. This cooling in the case of gasoline generally amounts to around 15 deg. cent. (27 deg. fahr.). In the case of alcohol, however, due to the higher heat of vaporization per molecule and the larger number of molecules to be vaporized, this factor becomes about 50 deg. cent. (122 deg. fahr.).

The *length* of the horizontal lines on Fig. 2 therefore indicates the temperature to which the air and fuel must be separately heated in order that after vaporization and the resultant cooling they shall have just the proper vapor-pressure to make starting possible.

A combination of these three factors, as indicated graphically in Fig. 2, shows that if the paraffin hydrocarbon has a given ease of starting at —2 deg. cent. (28 deg. fahr.), the benzol would have to be heated to +4 deg. cent. (39 deg. fahr.) and the alcohol to + 66 deg. cent. (151 deg. fahr.) to give equal ease of starting, in spite of the fact that their boiling-points were identical within a degree. The *absolute* temperature at which they would start depends of course upon other factors, such as the compression, etc.

The above-stated enormous difference between two fuels of the same boiling-point illustrates very clearly the futility of the present type of boiling-point specification to cover the varying types of motor fuels with which we will have to deal in the near future. Even for ordinary mixtures of paraffin hydrocarbons with similar heats of vaporization, etc., the custom of looking upon the initial-point as the determining factor in the ease of starting is indefensible, except for the rare case where the engine cylinders themselves are flooded with a large excess of the liquid fuel, so that the air is saturated with the fuel without appreciable change in the composition of the remaining liquid. The much commoner practice of using a choke or injecting gasoline into the manifold results in the vaporization of probably one-fourth or one-third of the fuel, and the vapor pressure of the liquid remaining thereafter is the determining factor in the volatility, so far as it affects the ease of starting. Again, this does not correspond to the 25-per cent point or the 33-per cent point on the ordinary distillation-curve, but it is rather an effective integration of the lower end of the curve when, say, 25 or 33 per cent of the gasoline has been distilled off into an airstream which is in contact therewith.

Alternative Apparatus for Determining Volatility

For an approximation probably covering most hydrocarbon fuels without serious error, we have found it possible to obtain a similar type of equilibrium solution by modified procedure, using the apparatus shown diagrammatically in Fig. 3. In this case we start with an empty flask in the oil-bath and continually run in 10 parts of fuel and distill off three, the remaining seven parts gradually filling the flask. If this is done carefully the boiling-point remains practically constant, once the flask is full enough to cover the thermometer. By the same method of reasoning as that used in the previous discussion the composition of the liquid in the flask corresponds to that of a drop in a manifold from which 30 per cent of the fuel has been evaporated, which may be taken as an average condition for starting in cold weather by the use of a choke or priming in the manifold.

In this case it is more difficult to regulate the input of the fuel by hand, since instead of maintaining a constant level we must now keep the ratio of the incoming

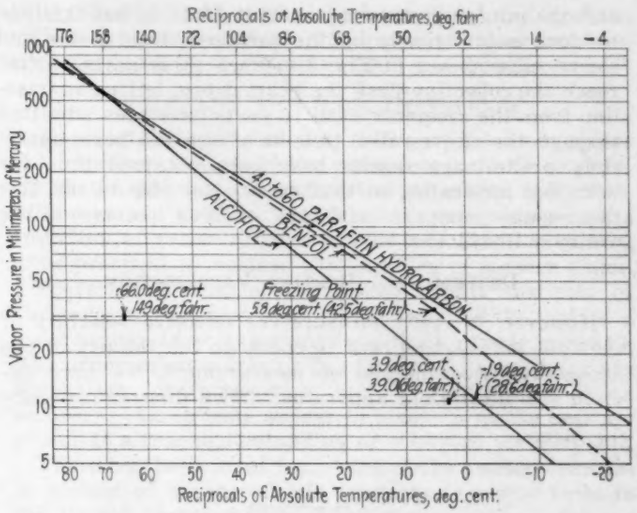
Reciprocals of Absolute Temperatures, deg. fahr.
176 158 140 122 104 86 68 50 32 14 -4
1000
500
200
100
50
20
10
5
Vapor Pressure in Millimeters of Mercury
40 to 60 PARAFFIN HYDROCARBON
ALCOHOL
BENZOL
66.0 deg. cent. 149 deg. fahr.
Freezing Point 5.8 deg. cent. (42.5 deg. fahr.)
3.9 deg. cent. 39.0 deg. fahr.
-1.9 deg. cent. (28.6 deg. fahr.)
80 70 60 50 40 30 20 10 0 -10 -20
Reciprocals of Absolute Temperatures, deg. cent.

Fig. 2—Vapor-Pressure Curve Plotted to the Logarithm of the Vapor-Pressure and the Reciprocals of the Absolute Temperature

The Advantage of Plotting the Vapor-Pressure Curve in This Way Is That a Straight-Line Form Is Obtained and the Heat of Vaporization of the Fuel Determines the Slope of the Line

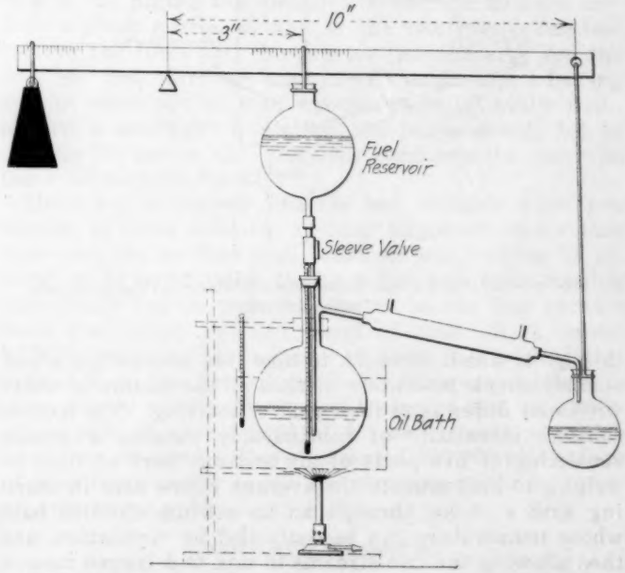

Fig. 3—Apparatus for Determining the Volatility of Motor Fuels

and the outgoing streams constant 10 to 3, but this can be done automatically by the balanced-beam device and sleeve-valve shown in Fig. 3. When three parts of fuel reach the collecting-flask the beam drops, letting in gasoline from the reservoir until 10 parts have been admitted through the sleeve-valve, thus balancing the beam again. Only preliminary results have been obtained thus far with this apparatus, so that we are not able to say how the results compare with the various points on the ordinary distillation-curve.

Determining Partial Vaporization

However, to really measure the effective volatility of the fuel for starting, and to check up the validity of the above-suggested method of measurement, we have devised still a different apparatus, shown diagrammatically

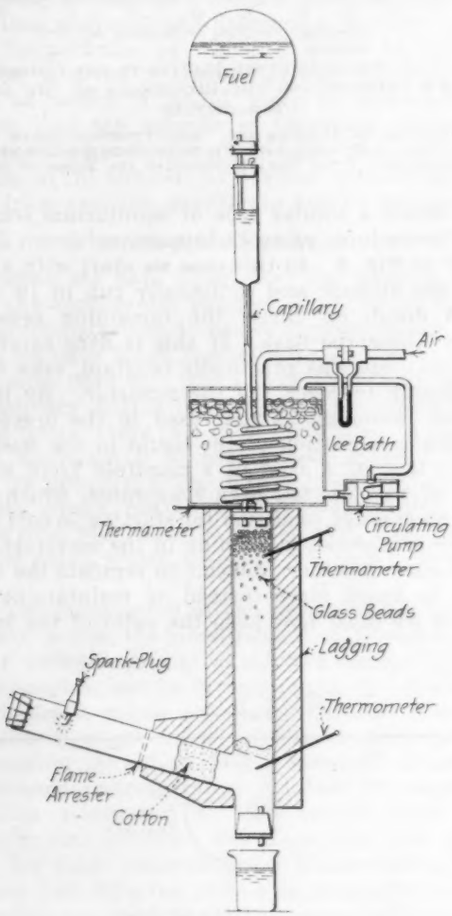

Fig. 4—Apparatus for Determining Partial-Vaporization Temperatures

in Fig. 4, which attempts to take into account by a reasonably simple laboratory method all the factors in which fuels may differ as to their ease of starting. The method consists essentially of continuously passing a stream consisting of five parts of air and one part of fuel, by weight, to approximate the average ratios used in starting with a choke, through an ice-calcium chloride bath whose temperature can be controlled by circulation, and then allowing the two streams to mix in a lagged column of glass beads. By this means the gasoline is cooled by evaporation as it would be in a manifold and the air becomes saturated with the lighter constituents of the fuel. All the *liquid* fuel passes out at the bottom, suspended drops being removed by the plug of cotton. The stream containing the vaporized portion of the fuel then passes a spark-plug which is operating continuously. The temperature of the ice-calcium chloride mixture in the bath is then gradually raised until the first ignition in the exit tube is secured, and the temperature of the air leaving the ice-bath at that time, which should be practically identical with that of the fuel and the bath, is taken as the effective starting-temperature of the given fuel.

Cooperation Sought

As indicated above, we are only now starting work on the measurement of the effective volatility by these methods and can say nothing as to their validity or, indeed, as to whether the apparatus may not require considerable modification to give reliable results. I am presenting these preliminary results and ideas at this time, however, in the hope that both producers and consumers of motor fuels may realize the inadequacy of present methods of testing and specifications, and that many laboratories may unite in trying to work out testing methods that really measure the properties in which we are interested.

If satisfactory tests based on these methods can be worked out, it will do away entirely with the need for specifying five points on the distillation curve. We will require just two tests, one for starting volatility and another for what we may call "distribution volatility" or "effective end-point," which also largely determines economy and crankcase dilution.

As I have indicated, our laboratory has no desire to stake out this field of investigation for itself, but rather hopes that as many laboratories as possible will follow up the suggestions and make such improvements as may occur to them until enough data are collected to make possible the evolution of a definite standard method of conducting the tests. We will be more than glad to cooperate with other individuals and laboratories to this end.

H. L. HORNING

REPRESENTING the National Automobile Chamber of Commerce and the Society of Automotive Engineers, H. L. Horning gave an address on the responsibility of the petroleum and the automotive industries to the public. He said:

No industry should make the error of assuming that its own house is swept clean and it is therefore proper to say that if motor fuel and lubricating oil marketed today are not perfect, there are many details of engine design, construction, sale and service that can be improved. There are limitations beyond which petroleum technologists cannot go, due to the physical and chemical nature of the petroleum products and to economic influences. There are likewise limits beyond which the automotive engineers cannot go, set by the laws of mechanics, thermodynamics, chemistry and physics, and the peculiarities of human nature. During the last two years the automotive industry has endeavored to vaporize fuels more effectively, and there has been an effort on the part of the petroleum industry to arrive at uniformity in fuel specifications.

The efforts of the automotive industry to vaporize the fuels that have been available in the last few years cannot be considered entirely successful. Even the cars that it is believed have the best systems may show more liquid in the crankcase after running 500 miles than at

the beginning. Oil consumption can be measured only by the amount of oil supplied since the last complete filling after draining. There is no definite way to tell how much real lubricating oil is used as such, between two fillings. The dilution of lubricating oil by the unvaporized and partially burned fuels is considered by many of the leading automotive engineers a measure of the failure to vaporize, and of the decreasing volatility of the fuels. The wide variation in the distillation curves of the fuels reported on by the Bureau of Mines in its last fuel survey indicates that there is no single known device that will vaporize both the lightest and the heaviest of these fuels in an equally satisfactory manner. The service departments and engineers of some companies are at the very end of their technical resources in countering the results of the decreasing volatility.

It may be well to consider what fundamental characteristics of fuels, lubricating oils and engine design made possible the petroleum industry with its vast trade in motor fuels and lubricating oils, and the automotive industry producing passenger cars, trucks and tractors.

FUEL CHARACTERISTICS

(1) Liquid fuel of high volatility
(2) Fairly uniform viscosity
(3) Chemical purity
(4) Stability of chemical structure
(5) High energy-content
(6) Wide marketing at a low price

INTERNAL-COMBUSTION-ENGINE CHARACTERISTICS

(1) Reliability of four-cycle design
(2) Well understood design
(3) Easy operation by persons of a widely varying intelligence
(4) Successful operation under greatly different conditions
(5) Accessibility and ease of repair
(6) Low cost of maintenance
(7) Light weight
(8) Low selling price, relative to the means of a large number of people to whom the economic value is great

CARBURETERS

(1) Reliability in metering, atomizing and vaporizing the fuel
(2) Simplicity and low number of parts easy of adjustment

IGNITION

(1) Reliable spark-plug easily cleaned
(2) Simple, practical generating system

LUBRICATING OIL

(1) Sufficient stability to prevent disintegration or vaporization
(2) Sufficient body to keep moving elements apart
(3) Adequately low internal-friction or viscosity
(4) Wide marketing at reasonable cost

LUBRICATING SYSTEM

(1) Practical lubrication of moving parts with a fairly wide range of oil qualities
(2) Distribution of oil in satisfactory quantities
(3) Assured practical lubrication over wide ranges of temperature, load, speed, service and neglect

All the years of development and experience from 1900 to 1922 have not shown that we can deviate in the slightest degree from these fundamentals without lowering the economic value of automotive apparatus to the public.

I have asked a great many well-informed men where they thought the industries would be today if, instead of utilizing the reliable four-cycle engine and the volatile fuels, we had built the Diesel engine, with which volatility, the carbureter, the spark-plug and the ignition system are not necessary. The average answer has been that we would be at about our 1903 development.

Volatility the Main Dependency

The volatility of the 1900 to 1910 gasoline made up for the imperfect design of the carbureters of those days. Of all the physical characteristics of motor fuel, volatility was and still remains our main dependency in the operation of motor vehicles of the type that has proved to be practical in meeting the demands of modern times.

Professor Wilson, of the Massachusetts Institute of Technology, has done our industries and the public a great service in pointing out technical methods by which the condensation points of the vapors of fuels of various distillation characteristics can be determined with accuracy. These tests appear to many to be the best approach to a true understanding of volatility yet available.

There has been great complaint of the sudden increase in content of highly volatile fractions in motor fuels in the United States during the last summer and fall, as evidenced by the low initial boiling-points given in the Bureau of Mines' reports and by a variety of experiences recognized by motorists who know and suffered by those who did not know. Nearly all modern carbureters meter the liquid fuels through nozzles or orifices of various shapes which give accurate results under definite predetermined conditions. The gravity and the viscosity of the fuels are of most striking economic importance in this connection. Viscosity is determined by the internal-friction of the fluid. In a nozzle, viscosity governs the amount of fluid flowing under given pressures and temperatures. Temperature changes the viscosity in a rapid and marked manner.

Gravity and Viscosity

There is a difference in flow of from 5 to 25 per cent with the carbureters now in use between temperatures of 60 and 90 deg. fahr. in the case of fairly volatile fuels. There is a great change in viscosity with changes in gravity and volatility. There is a difference of 10 per cent in the flow of the fuels in the extreme cases of the Bureau of Mines' report. The higher the gravity, or molecular weight of any fuels of similar origin or structure is, the higher the viscosity is, and the less the flow with a given nozzle, as well as the volatility. The less volatile the fuels are, the greater the viscosity and the less the flow through any given nozzle are. During periods when you oil men want to work off heavy fuels, or have a shortage of volatiles, the public simply has to open up the gas to run. May the Lord help the man who has a fixed-nozzle outfit!

However, in periods like the last summer when you wanted to move volatiles, nothing happened except that unawares the average man found he was making 13 instead of 15 to 16 miles to the gallon and some touring individuals had to walk 5 miles or so for fuel because their fuel supply ran out ahead of time. It is impossible to estimate the amount of good fuel wasted this year due to the low viscosity attending your effort to move highly volatile fuels, and I suspect that an appreciable part of your record of a recent month in which you were reported to have marketed 500,000,000 gallons of gasoline was due to its low viscosity in the hands of an unknowing public.

Uniformity Essential

Now this fact is above all others the one that imposes on the petroleum industry the entire weight of a high

moral responsibility for a uniformity in the marketing of motor fuel, both as to volatility and as to viscosity. It is not my place to moralize with you, but it is fitting for both our industries to ask if it is fair, I will put it even stronger, American in spirit, to foster a trade wherein the public is served with so varying a quality. I wonder how many oil companies took the trouble this last fall to have their tank-wagon and service-station men tell their customers they could cut down the fuel feed. A simple service this but, I fear, a neglected one. I make a plea for uniformity in volatility and viscosity, and can promise an improvement in mileage and a satisfactory saving in first cost and up-keep of automotive apparatus, if you will see that this uniformity is approached.

Let us now consider the total losses imposed by fuel and engine limitations. If there were no losses whatsoever, it would be possible to get a brake mean effective pressure of 582 lb. per sq. in. of cylinder area. The highest attainable brake mean effective pressure is, after all losses are deducted from the maximum possible pressure, only from 25 to 15 per cent of this figure, depending upon the type of engine and of fuel.

Chemical Stability

Referring back to the fundamental analysis of the characteristics of motor fuel that made our industries possible, I call your attention to the matter of chemical stability, that quality which permits the fuels to be burned at high compression and in such an orderly way as to give high thermal efficiency. I will not dwell on this matter more than to say that the tendency to knock arising from chemical instability is largely responsible for the low compression commonly used and for a loss of 23 to 50 per cent in mileage. This fuel defect can be overcome to only a relatively small extent by improvement in engine-cylinder design. The great deposits of carbon encountered in the use of latter-day fuels is due in a large measure to this Bolshevik tendency of the fuel. With lower volatility comes increased knocking, necessitating lower compression and lower efficiency. With the knocking tendency eliminated, smaller engines could be used and operated more nearly at their full-load capacity. Messrs. Kettering and Midgley have accomplished results in the last year along the lines of discovering correctives for this defect in the fuels, which in time cannot help being considered epochal.

The petroleum industry has fallen into the error of vindicating the lower volatility on the ground of a higher energy content of the fuel expressed generally in British thermal units. The high energy would be gratifying if available. Some facts of importance to the petroleum industry were arrived at this year by Harry Ricardo in a very thorough investigation of fuels for the Asiatic Petroleum Co. of Great Britain. These facts may be stated briefly as follows:

> In general, when all hydrocarbon fuels are tested under the same conditions, in which sufficient heat is applied to vaporize them, and at compressions at which the most unstable will not detonate, it is found that they give the same power and thermal efficiency within 1 per cent, and this power is attained with a mixture giving complete combustion. There are many characteristics of the fuel, as well as limiting factors in engine design, that make the heat energy available only in a limited degree. Claims for great power in fuels marketed are of doubtful accuracy. Those fuels that have the higher volatility and stability always tend toward a greater return from the energy in them than those of low volatility and inferior stability.

Questionnaire Results

I wrote fourteen executives engaged in the automotive industry, who not only are leaders but have an economic as well as an engineering appreciation of the questions involved in the fuel problem. I will give a recapitulation of their answers. I am not going to draw any conclusions from them for you, for I believe the individual answers should have your serious consideration. Abbreviating an observation set forth by Schopenhauer, you will probably act on these, on an impulse having its origin in your character, rather than in the influence of your knowledge of the facts.

The questions and answers are as follows:

Question 1—What percentage of all the fuels wasted is due to the high end-point?

Answer—The greatest losses occur during the starting from cold, running, idling and accelerating.

The losses are least with highly heated vaporizing systems and may show a difference of only 3 per cent.

With the average motor car 30 per cent of the waste is due to high end-point.

Lower end-point would reduce crankcase dilution. One engineer says that there is a direct waste of 20 per cent due to high end-point in the average engine, but that the indirect result of high end-point may be as much more waste.

One claims a 60-per cent loss during the starting and warming-up period, or generally during cold-period running.

With highly efficient manifolds Navy-specification gasoline can be made to operate with very little loss, as compared with 350-deg. fahr. end-point fuels, if it is kept uniform.

Question 2—What percentage of fuel waste is due to the effort of the user to prevent knocking?

Answer—Probably 2 per cent of fuel is wasted by rich setting for heavy pulling, and 28 per cent by best setting for power.

Some waste is due to improper setting of the spark.

Question 3—What percentage of fuel wasted is due to the necessity of low compression-ratio?

Answer—An increase in mileage of from 30 to 100 per cent is possible with higher compressions.

Question 4—What percentage of fuel waste is due to overall conditions?

Answer—Motor cars would use 16 per cent less fuel if uniformity in fuels prevailed.

There is a 28 per cent loss due to the effort to get maximum power.

It is possible to increase the mileage 60 per cent with uniform fuels.

Question 5—Does the standard Navy specification, 120 to 440 deg. fahr., represent a practical fuel today?

Answer—It is a satisfactory standard for a uniform fuel and the limit for present automotive equipment. It can be handled well with good hot-spot manifolds. One engineer says that it is practical but not desirable for average cars or conditions. One advises the installation of a separate tank for starting-gasoline of 72 deg. Baumé for winter.

Question 6—Is the last 10 per cent coming off from the distillation of Navy-specification gasoline responsible for 10 per cent of the power actually delivered, or is there a loss due to the difficulty of vaporizing it?

Answer—The energy of last 10 per cent of heavy fuel can be made entirely available in well-heated manifolds. There is about a 10 per cent loss, not necessarily consisting of the last 10 per cent, but largely due to it, in the average manifolds with

higher end-point fuels. Some engineers claim that the last 10 per cent of fuel is of no value and that 400 deg. fahr. is the maximum end-point for practical fuels.

The complaint today is of much higher end-point.

QUESTION 7—If the end-point of fuels were increased 10 per cent, what percentage of the energy in the 10 per cent of heavy fuel would be available in the average car now in operation?

ANSWER—Little of the 10 per cent of energy would be available with cold manifolds and during starting and cold running even with hot manifolds.

With uniform fuels an engine could be produced to burn fuels of 480-deg. end-point, but no engine is so equipped now.

QUESTION 8—Is there a growing demand for fuels containing aromatics and naphthenes?

ANSWER—Yes, even at a higher price.

QUESTION 9—If fuels had an end-point of 350 deg. fahr., would less gasoline be consumed per mile? What percentage less?

ANSWER—There would be more mileage, up to 25 per cent, with proper readjustment of carbureter.

There would be a saving, particularly in starting and in cold operating.

Without change of carbureter adjustments there would be a decrease in mileage with light fuel in summer, but an increase in winter.

With proper manifolds there would be no difference after warming-up.

QUESTION 10—If large quantities of fuel with aromatic content were available, would the public drift to it even at higher prices?

ANSWER—The great demand will always be for lower-priced fuel.

There will be a demand for any fuel that will not knock. In the case of engines that knock easily the tendency will be to use the aromatic fuels; cheap petroleum products will be used for those engines that do not knock easily. Those whose engines develop knocks will go to aromatics when the price is not over 10 per cent above the lowest price for fuel. There is a marked growing demand for fuels with aromatic content.

QUESTION 11—What is the percentage difference in the length of service for pistons, rings and cylinders, assuming that 100-per cent service is given with fuel of 350-deg. end-point? The service under consideration is with 440-deg. end-point.

ANSWER—Pistons of out-of-date model will wear twice as long with 350 as with 440-deg. end-point.

With a good hot-spot manifold, they will last 10 per cent longer.

With high temperature of mixture and no detonation there will be little difference; but the fuel would have to be uniform.

Very often dust is the cause of wear assigned to high end-point fuel.

QUESTION 12—How much more lubricating oil will be used, due to dilution on the cylinder walls and in the crankcase, when using Navy-specification gasoline than when using 350-deg. end-point fuels?

ANSWER—Dilution increases with end-point.

The oil has to be changed more frequently with increase in end-point; hence there is greater oil waste.

There is little dilution with 350-deg. end-point gasoline.

Efficient hot-spot manifolds reduce dilution and the consumption of lubricating oil.

Dilution occurs mostly in starting, in cold-weather running and during warming-up.

On some engines the lubricating-oil consumption will be double with 440 as compared with 350-deg. end-point gasoline.

Design can control this for a uniform fuel.

QUESTION 13—What mileage is lost due to poor compression resulting from the use of 440-deg. end-point fuel, compared with 350-deg. end-point?

ANSWER—In engines without vaporizing systems the loss is about 25 per cent.

In engines equipped with usual designs of hot-spot it will not exceed 10 per cent.

In engines in which the intake manifold is raised to very high temperatures with some of the products of combustion, it is possible to burn 530-deg. end-point fuel without defects in compression.

Reverting again to the fundamental analysis of the cause of the rapid development of our industries, I want to present a review of the conditions that confront the sales, service and engineering departments of a company whose apparatus must meet the varying fuels which your decisions dictate. Let me dispose of the carbureter by stating that long ago it lost its originally intended function of vaporizing the fuel. As an instrument for metering the fuel and air it has reached a high state of development. Nothing except a manual control of fuel flow has been devised to meet the widely varying viscosities imposed by temperature conditions of our climate and changes imposed by the engine; or the varying viscosities in the fuels on the market. If a fairly uniform volatility could be attained by the petroleum industry, a fixed-jet carbureter could be used that would remove one of the causes of greatest waste, namely, a gasoline adjusting-valve in the hands of an unskilled, forgetful and in a measure irresponsible public. This would eventually save gasoline in a considerable quantity. The certainty of a uniform fuel would permit manufacturers to solve problems such as dilution of crankcase oil and rapid wear of parts.

Temperature variations can be met practically with uniform fuels by vaporizing devices of high overall efficiency, excellent distribution being attained. The devices cannot be efficient with a wide variation in volatility and viscosity.

SIMPLICITY A PRIME CONSIDERATION

The automotive industry has found that it cannot depend upon the intelligence or care of the public for complicated adjustments. The devices that make good are those in which there is no adjustment. The most successful engine is that which continues to operate without adjustments over long periods. Whether this is right or wrong is immaterial. The economic significance of this simple fact overshadows every other phase.

The loss due to interrupted service of automotive apparatus is, irrespective of cause, a loss to national wealth which is sustained by the public in general and by the automotive and the petroleum industries in particular. This is a most significant feature of our mutual problems. If we make highly technical apparatus to meet the rapidly varying qualities of fuel, we will defeat our very object in the hands of the public.

The replies to a questionnaire sent to 20,000 car owners by the National Automobile Chamber of Commerce indicate that the preferential basis on which cars are bought is as follows:

	Per Cent		Per Cent
Endurance	18	Flexibility	7
Comfort	11	Hill-Climbing Ability	6
Price	10	Endorsement	6
Appearance	9	Specifications	6
Economy	8	Speed	5½
Service	7	Appointments	5½

We plead with you for uniformity of gasoline volatility on the ground of the improvement that will come in the operation of the apparatus in reference to endurance, comfort, economy, service, flexibility and hill-climbing ability, the combined percentage of which is 57.

More than anything else the reliability, what the public calls endurance, is responsible so far as the engine is concerned for the rapid growth of the industry. From a practical standpoint that engine is the best which will give satisfaction even when it is in a dilapidated condition. The service value outweighs the matter of efficiency. As times change and fuels rise in price the question of efficiency will gain in importance.

Lubricating Oils

Lubricating oils, which were so important at the beginning of the industry, have become one of the most vexing problems with the decline in fuel volatility. The president of one of our best known motor car companies has made the statement that during the years 1918 and 1919 the problems of piston and cylinder lubrication cost that company $1,000,000 in service. In the last year several firms have rebuilt their engines as many as three times to stop oil-pumping. Lubricating oils have been variable in viscosity. The automotive industry would like to cooperate with the petroleum industry in arriving at a reasonable specification for certain services and then have the petroleum industry stick to it. We regret to state that the variations in lubricating oils in the last 5 years, even among those most widely used, are drastic. As fuels have decreased in volatility it has been increasingly important to have oils of greater body to offset the dilution. Heavy lubricating oil is an important cause of loss in mechanical efficiency and of increase in fuel consumption.

Many systems of lubrication have been developed. The final forms of these must

(1) Give satisfaction irrespective of oil and fuel qualities
(2) Require little or no attention by the public
(3) Be almost automatic

These factors tax the best ingenuity of the automotive industry and lead to very unfavorable compromises. Here again uniformity in fuels and oils would be of immense value in the operation of engines.

Saturation Point and Fuel Famine

In conclusion, let me assure you that the automotive industry believes that it will be many years before there will be saturation of the market for passenger cars, trucks and tractors. In the last year many new uses have been found for the internal-combustion engine. During the coming year probably more cars will be produced than were produced last year, when the output was approximately 1,200,000, of which 800,000 were Fords.

There is a growing belief in the automotive industry that there is no real danger of a fuel famine. The immense reserve in technical and scientific possibility promises that the incentive alone will be needed, as the near-famines threaten, to meet the demands of many succeeding generations. There is, however, no justification for the present waste on the basis of no threatened shortage of fuels.

A study of the natural processes by which the energy of the sun was stored up millions of years ago in the form of what we call petroleum indicates that by scientific methods the energy reaching us can be caught and marketed each year, as in the case of food. This is the resource to be depended upon when new fields shall have ceased to respond to the incentives that actuate fortune-hunters.

Fuel Marketing Policy

The automotive industry offers for your serious consideration the following policy in the marketing of motor fuel. If you will see that the poorest fuel offered for sale is close in volatility and viscosity to Navy-specification fuel, the most disturbing variable will be eliminated from the fuel problem before the automotive industry. Your undertaking to do this will insure greater satisfaction in the operation of the 10,000,000 cars out today. The life of the wearing parts will be prolonged. This uniformity will go a long way toward solving your lubricating-oil problem. You will by this act stabilize the growth of the automotive industry, conserve a great quantity of fuel, decrease the engine-upkeep cost, and reduce the depreciation rate.

I believe that business in America is today on the highest moral plane that the world has ever known. I believe that business and particularly big business is being conducted on a thoroughly sound ethical basis. I believe that more transactions are being conducted on the basis of good faith between individuals than has been thought possible. I believe that there is a new aristocracy among men and nations who prove daily that a man's word is the limiting factor in the value of a contract or a treaty. I rest the case on this faith, leaving it to the decisions of your conscience.

I would have you consider carefully an economic truth. No transaction is economically sound that does not recognize two profits, that of the buyer as well as that of the seller. It is the buyer's profit that in the long run determines the measure of the seller's prosperity and stabilizes the market. It takes strong conviction and splendid courage to accept this truth at its full value and to act on it. Yet our industries cannot serve the public fully by adopting any compromise that will not insure to the public the maximum returns arising out of uniformity in fuels and lubricating oils and the very best engines that this uniformity will promote.

ROADS

GRANTING that the preparation of the roadbed has been properly done, many kinds of highway surface will give excellent service. The element of time is important. There are so many miles of highways to be constructed and their cost will be so enormous that the most careful and detailed study of each highway project must be made to provide, at the lowest possible cost, highways that will give satisfactory service and can be maintained without undue depreciation under the traffic that is to use them. Many times the question has been asked, what type of highway is best? The answer is, there is no one best kind or type of highway surface.

Subgrade, drainage and present and prospective traffic, vitally affect the determination of the standards of construction to be used. There must be a careful analysis of the engineering and economic conditions for each particular case to determine the kinds of material that can be used successfully, and after these facts are determined the various types of construction that can be used economically should be brought into competition to secure the best possible results. The cost must always be considered in determining the type of highway surface to be used, and the allowable cost must be determined by the traffic that is to be borne. Local conditions vary to such an extent that very careful consideration must be given to all the factors that have a bearing on each individual project.—T. H. MacDonald.

The Trend of Aviation Development

By J. G. VINCENT[1]

GROUPING the influences that are retarding the development of aviation into five specified divisions, the author, who took a prominent part in the development of the Liberty engine and other wartime aviation activities of the Government, discusses each one, in the order of their importance, in an effort to point out the limitations that exist as differentiated from misconceived non-existent limitations and to indicate remedial measures stimulative to a provident trend and vigorous growth of aviation.

The subjects of adequate landing-fields, the real and imaginary dangers of flying, single and multi-engine airplanes, passenger comfort and commercial considerations are treated at some length, prefatory to an outline of the trend of airplane design and an enumeration of powerplant requirements. With an outlook toward future development, the essentials of air transportation are commented upon specifically under four divisions inclusive of landing-field policy and Governmental mail-contract patronage and experiment-station helpfulness as aids to successful progress.

IN view of the embryonic state of the art of aeronautics, I am inclined to attack the subject of the trend of its development with more or less diffidence, recognizing that future developments may rudely shatter such prophecies as I may have the temerity to submit. However, the best we can hope to do is to try to visualize ideal attainments as we conceive them in the light of our present knowledge; with such concrete examples before us we can speculate more accurately on the future course of development.

Before entering into a discussion of the various elements of the airplane, I would like to review the present art of flying, pointing out the limitations that exist and attempting to eradicate misconceptions as to limitations that do not exist. Whenever the subject of flying is under discussion we hear queries as to why aviation does not progress, why the Government does not do this or that to encourage aviation. I believe firmly that aviation is developing as fast as the state of the art and existing conditions will permit. While I must say that at times the outlook is by no means encouraging, yet on second consideration it is apparent that aviation is following the same inflexible rule that has governed the development of all our transportation facilities. Aviation *must* be made to pay its way; it cannot be coddled on Government subsidies; it cannot be nursed along in half-hearted competition with the older forms of transportation; it must prosper on its own merit or not at all. The time is bound to come when we will consider, not whether we can afford to use the plane, but whether we can afford *not* to use it. The steamboat, the railroad, the automobile and the motor truck have all had to fight and fight hard for recognition, and the airplane will have to continue to fight its battle until a truly successful state of development shall have been reached.

The influences that are retarding the development of aviation can be grouped as follows, in the order of their importance: (*a*) lack of landing-fields and other facilities for storage and repair; (*b*) the more or less prevalent impression of the dangers connected with flying; (*c*) the lack of comfort for passengers; (*d*) the unsuitability of the average plane for commercial purposes; and (*e*) the difficulty of interesting capital in organizing aviation transportation due to (*a*), (*b*), (*c*) and (*d*). I propose to take up each of these factors in turn and to attempt to point out how, in my estimation, the conditions cited can best be remedied.

LANDING-FIELDS

The absence of suitable landing-fields in proximity to our larger cities represents the one obstacle that the aviation industry cannot hope to remedy unaided. Federal or municipal aid in this direction is essential and is warranted just as much as is the expenditure for good roads, which will total approximately the fabulous sum of $600,000,000 in 1921. None of this amount is contributed specifically by the automobile industry; the country at large pays and receives the benefit from it. Similarly, it is not to be expected that the struggling aircraft industry can take any part in building up a system of landing-fields throughout the country. This phase of the situation was covered thoroughly in the report of the National Advisory Committee for Aeronautics, which was endorsed by the President and submitted to Congress last April.

Before leaving the subject of landing-fields, I would like to record a suggestion that I believe will be very much appreciated a few years hence. That is, landing-fields should in all cases be equipped with permanent hard-surfaced runways of ample width and length and preferably arranged in the form of a cross so as to permit of landing in at least four directions. Commercial aviation will never be entirely successful until flying can be carried on more or less without regard to weather conditions; at this time soft landing-fields are responsible not only for the postponement of many flights, especially in the spring and winter months, but also for frequent damage to airplanes caused by "nosing over" in soft fields. The use of hard-surfaced runways such as are found at McCook Field, Dayton, Ohio, appears therefore to be vital to the success of all-the-year-'round safe flying. Furthermore, these runways offer excellent landmarks when viewed from the air, and it is easier to bar spectators from these well defined areas than from the field at large, thus eliminating another source of danger.

DANGER IN FLYING

I have placed second in the list of influences retarding the growth of commercial aviation the more or less prevalent impression of the dangers connected with flying. These dangers can be classified as real and imaginary. We will consider each in turn, knowing that the real dangers must be overcome by new developments and improvements, while the imaginary dangers must be dispelled from the public mind by suitable propaganda that we can all assist in spreading. First and foremost of the real dangers is undoubtedly that of "stalling." Directly or indirectly, "stalling" is probably responsible for the greatest percentage of fatal crashes. Forward speed is, of course, essential to the sustentation of an airplane and for any given machine at any particular altitude there is a minimum critical speed below which the plane is unable to support itself and will fall out of control for such a distance as is necessary to bring it up

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to its minimum flying-speed. This stalling speed is given in terms of *forward* speed in the line of normal flight. Without going too deeply into technicalities it may be stated that in cases where the airplane is not advancing in a direction parallel with the airstream, the stalling speed will be considerably raised since the airfoil section is designed to give the maximum lift when the airstream is substantially normal to the wing.

Sufficient "flying" speed is therefore essential at all times to the safe control of an airplane; and this speed can be attained either from the motive power of the engine or from the force of gravity in the case of a glide. In the case of all machines in use at the present time it has been found necessary, to permit of proper maneuvering when making a landing or taking-off, to provide an excess of control surface, by which I mean that the lateral, directional and longitudinal controls represented by the ailerons, rudder and elevators are of such ample surface that they are effective at speeds below those at which the plane is capable of supporting itself. The consequence is that it is at all times possible for the pilot to manipulate the controls so as to decrease the machine's forward speed down to a point where it ceases to be subject to his control due to lack of sufficient lift developed by the wings. The pilot can then recover control of the plane only by speeding up the propeller if the engine power is available or by gliding a sufficient distance to obtain the necessary acceleration. It is quite evident that if this "stalling" condition is met within a few hundred feet of the ground with a dead engine, the consequences will be serious, since the height is insufficient to permit of accelerating the plane in a glide to the required minimum speed. This possibility of a pilot being able to bring about a stalling condition, which is manifested also in such maneuvers as side-slipping and tail-spinning, represents a phase of aviation that must be eliminated, I believe, before we can say truthfully that air transportation is as safe as the other modes of travel. Some may argue that the expert pilot will never stall a plane even in an emergency, but unfortunately experience has shown that in the great majority of cases when the engine fails shortly after taking-off, which is one of the worst contingencies encountered in flying, even the most level-headed pilot will instinctively try to bring the machine back to the starting-point, instead of "nosing her down" instantly, regardless of the nature of the landing space available directly ahead. Needless to say, if the plane has but limited altitude, this latter maneuver is the only means of maintaining flying-speed and avoiding a stall. Loss of flying-speed is of course not the only cause of a stall or its equivalent; atmospheric conditions, especially just previous to or during a storm, are sometimes responsible, due to eddy currents or sudden variations in the density of the air, which in effect necessitate an instantaneous increase of the minimum flying-speed which will enable the plane to support itself.

The popular conceptions of the dangers of flying center around chiefly the possibility of the engine stopping in the air. As I have just pointed out, engine failure can be regarded as extremely serious only during the few initial seconds after taking-off. A forced landing with a dead engine from any reasonable altitude over ordinary flat country rarely results in serious consequences. At an altitude of 5000 ft., for example, and with a gliding angle of 1 in 10, the pilot has a choice of territory comprising an area of about 280 sq. miles or a circle of 19-miles diameter in which to find his landing spot, and he has ample time to study wind direction, ground obstacles, and the like, before making his choice. Of course, in cross-country flying it is necessary at times to fly over territory on which it would be very hazardous to attempt a forced landing; such as mountain ranges, large bodies of water and rolling country; in such cases the pilot should be guided by common sense and if necessary make a reasonable detour to limit the duration of flight over such territory, at the same time maintaining good altitude so as to have the advantage of a long glide in case of engine failure.

I am not at all ready to admit that engine failure in the air can be regarded as an unpreventable occurrence. As a matter of fact, the majority of engine failures are due to easily preventable causes and can generally be traced to failures in the gasoline, oil or water systems, which in turn are due to lack of coordination between engine and plane design. Unfortunately, these troubles cannot be eliminated entirely in practice until considerable flying experience has been obtained with the particular plane under consideration. In other words, with the expansion of commercial aviation, I would look for a great improvement in respect to the so-called "plumbing" troubles that are responsible, I may safely say, for 90 per cent of engine failures in the air. The automobile went through the same transition in this respect, roadside stops being due almost invariably to similar minor faults.

Failures of the plane structure in the air are now practically unknown. Assuming that a given design has been carefully calculated with ample factors of safety, that suitable static tests of wing-truss, fuselage and controls have been made and that reasonable care is exercised in maintenance and inspection, there exists only a most remote possibility of danger due to the collapse in the air of any part of the plane structure.

We have now considered the elements of danger connected with commercial aviation and are in a position to judge to what extent the popular conception is justified. We must first admit that the results of stalling at low altitude are serious. If this could be obviated, a great step forward in the development of safe air-transportation would be made. Once good altitude has been reached, the element of danger becomes negligible and with a properly designed plane and a well tested and reliable engine properly installed, air transportation can be said to be, if anything, safer than any other mode of transportation. The possibility of engine failure will ultimately become negligible, but this can be brought about only by a large amount of flying. Planes, even today, are perfectly satisfactory from the standpoint of structural safety and improved constructions are being rapidly evolved.

Single and Multi-Engine Planes

It may be well to review at this point the relative advantages and disadvantages of single and multi-engine planes. A few years ago, before reliable engines were available in quantities, it was thought that the best way to guard against engine failure was to provide additional engines or rather divide up the powerplant into smaller units. Two-engine, three-engine and four-engine, and planes with even more engines have been built and successfully flown. A serious drawback to such arrangement is the necessity for providing a surplus of power in the complete powerplant, resulting in uneconomical operation; in the case of a two-engine plane, for example, it is desirable that each engine be capable of maintaining the plane in the air by itself. While the average plane in taking-off from a small field requires more than double the power necessary to sustain it in the air at its mini-

mum flying-speed, nevertheless two-engine planes as constructed heretofore have not been shown to have a factor of safety against engine failure sufficiently high to warrant the added complications. Of course, in many instances the powerplant demands have been in excess of the power of any proved engine and for that reason in large planes it has been necessary to install multiple units of smaller engines. I am not attempting to cover the whole question of single-engine versus multi-engine planes at this time but will state my belief that for intercity transportation over country providing a reasonable number of emergency landing-fields, the single-engine plane is undoubtedly the most desirable. The engine should, however, have 30 or 40 per cent more power than is required for normal cruising speed. For long flights over water, forests, mountains or sparsely inhabited regions, a two-engine plane undoubtedly offers additional security, provided either engine alone is capable of propelling the plane at a sustaining speed.

Summarizing, whereas air transportation offers some risks, these are by no means as numerous as is popularly supposed and in practically all cases they are preventable. Engine failure can never be said to be directly responsible for a crash unless it occurs at very low altitude. Undoubtedly the most serious unsolved problem is how to prevent a pilot from stalling a plane under stress of sudden emergency.

Passenger Comfort

The third factor militating against the progress of commercial aviation is the lack of comfort afforded passengers. This is a real handicap. Although it is not at all difficult to persuade the average person to take his first flight, this is generally accomplished in a spirit of adventure or curiosity. The usual comments made by the passengers upon returning to ground are that the sensation was nothing like what had been pictured; in fact, that the experience was rather mild. The noise of the engine and the propeller are severely criticized and if the trip was lengthy and at considerable altitude the cramped quarters and cold probably receive unfavorable comment. Of course, there have been introduced abroad, and to a limited extent here, planes offering enclosed passenger-accommodation that approaches the luxurious. Much more must be done in this respect, especially in this country where railroad equipment has been developed to a point where one can travel with practically all the luxuries of a hotel at his command. There is nothing inherently impossible in providing similar service through the air, but this would require ample capital and special design throughout.

Probably the most difficult problem lies in suppressing the noise of the engine and the propeller but this also must be done before air transportation can rival ground transportation on the score of comfort.

Commercial Considerations

The fourth unfavorable influence so far as the progress of aviation is concerned was given as the unsuitability of the average plane for commercial purposes. This is largely responsible for the difficulty in interesting capital in commercial-flying ventures. It is fairly well known how wartime machines have been built over in an endeavor to construct a peacetime passenger-carrying plane and also the indifferent results accruing from this procedure have been appreciated. Excellent planes have been built since the war for passenger carrying and many of these are giving splendid service abroad. But the costs of operation and maintenance, as well as the rate of depreciation, of these are so high that it is very doubtful whether any of the ventures based on their operation could pay their own way without the generous subsidies provided by enterprising foreign Governments.

Looking at this matter from a cold businesslike standpoint, we can see that the saving in time afforded by air transportation offers an inducement to the business or professional man that can be measured in just so many dollars. For example, there is a limited demand for extra-fast trains, say, from New York City to Chicago, and the saving in time is considered to more than offset the extra fare paid for this service. It is safe to assume that for still faster service a higher fare in proportion to the extra time saved would readily be paid. Unfortunately, there is a limit to the possible saving in time, due to the fact that long overland trips are invariably made overnight, the average business man considering a night in a Pullman not very much more of a hardship than a night in a strange hotel. The result is that to prove its worth air transportation must save *daylight* hours for the average traveler. Furthermore, even on comparatively short overland trips, of say 200 miles, the average man will prefer going aboard a train at 10 p. m., turning into his Pullman berth and getting up in the morning at his destination, the train having actually been moving perhaps only 5 hr. of the time. On such a run the real inducement to be offered by the airplane is the making of the round-trip in 4 hr., leaving a good part of the day available at either end of the journey for the transaction of business.

Finally, we come to the subject of interesting capital in commercial aviation. This is an extremely knotty problem for the reason that it takes considerable capital to demonstrate the possibilities of a fair return on an investment of this character. Furthermore, I believe that not even aviation's staunchest supporters will claim that commercial aviation can be made to pay from the start. There is bound to be a period of development and experimentation that will more than absorb all possible profits. Again, what protection is there for the pioneer? If it were possible for the Government to grant exclusive franchises over certain air-routes for extensive periods, there might be a chance of inducing capitalists to invest; but I hesitate even to suggest the possibility of such franchises. Without such protection the pioneers would be forced to develop at considerable expense the most suitable flying equipment, schedules, routes and many details of organization that competitors could duplicate a few years later, driving the pioneers, burdened with the heavy expenditures incurred during the development stage, out of business.

I have attempted to present the status of commercial aviation today in the United States and propose to consider now the general trend of plane and engine design.

Trend of Design

For the purposes of this discussion we will consider in turn the three principal elements of the plane, the wing truss, fuselage and powerplant. In reviewing design tendencies in these fields I propose to cover the ground rather broadly as it is the object of this paper to bring out some constructive ideas that may assist in some slight measure in the advance of commercial aviation in this Country, rather than to get into a discussion of the relative merits of different designs. At the outset let us decide what type of airplane it behooves us to consider in this connection. Of the two types, water and land planes, there is little question that the future of commercial aviation must rest chiefly with the latter.

There are some splendid but limited opportunities for the use of hydroairplanes and flying-boats along our coast and between our Lake cities, and these fields are being gradually developed. The chief advantage of the water machine rests with its ability to "land" on any suitable body of water, weather conditions being reasonable. The need for expensive landing-fields is obviated and the initial investment thereby reduced. On the other hand, the routes are necessarily restricted and the machines themselves are far less efficient than land planes due to the high parasitic resistance of the hull and pontoons. It is indeed a question whether land machines fitted with emergency flotation-gear are not preferable over water routes of not too great length; it may be remembered that all air transport across the English Channel is by land machines. Assuming, therefore, that our discussion is to be confined to land machines, what particular type should we consider as best meeting the immediate needs of commercial aviation? There are many conflicting aspects of this phase of the problem. From an operating standpoint we are justified in expecting that the lowest operating cost would be associated with rather large planes, having ample capacity for passengers and freight. On the other hand, the initial investment and risk of damage would be proportionately greater with the larger units. All things considered, I believe we can safely say that the smallest plane that can be economically operated and be made to pay in commercial service would have a capacity of about 10 passengers or approximately 2000 lb. of freight. While this may sound like more or less of an arbitrary conclusion, it is based largely on present-day knowledge of structural limitations.

Considering now the wing truss for such a machine, there are two general types of construction to choose from. The first is the older and conventional, externally braced, trussed type, generally of biplane form; the second is the more recent, internally braced, thick wing-section, generally associated with monoplane design. This latter type lends itself particularly well to all-metal construction. From the commercial standpoint there are many points in favor of the internally braced wing, chief of which are the decrease in maintenance and inspection costs, improved economy in operation due to improved aerodynamic performance and the ability to make quick repairs by replacing the entire unit. The possibility of storing fuel and freight in the wing is quite alluring, and the improved vision for the passengers must not be overlooked. All things considered, it is evident that the internally braced wing presents overwhelming advantages for commercial planes. Just what material should be employed in the wing structure is a question of less import. An all-metal structure offers theoretical advantages from an upkeep standpoint. On the other hand, it is necessarily more rigid than a built-up wood construction reinforced with suitable tension-wires, and the resistance to fatiguing stresses induced in the metal wing by the fine vibrations transmitted from engine and propeller is questionable. If ultimately crystallization is to set in and sudden fracture take place, the consequences might be exceedingly grave. Summing up, it is evident that the internally braced wing is exceptionally well suited for commercial planes, but that all-metal wings of this type will continue to be looked on with suspicion until a large amount of experience shall have shown that they have practically an unlimited life and cannot be said to depreciate with use.

All things considered, I think it is a fair statement to make that the question of a specific wing-truss is not a material factor in the advance of commercial aviation. In other words, all present standard forms of construction can be considered satisfactory for commercial purposes, although, as remarked above, some of the newer constructions will undoubtedly effect savings in upkeep and hence bring the air-transportation era one step closer.

Taking up the question of fuselage construction, we recognize that there exists a general tendency in design toward more rugged construction, considerable attention being paid to securing reduced cost of manufacture and upkeep. The built-up veneer trussed type appears to be giving way to the all-steel truss type. One form of construction which seems to be excellent is that in which the fuselage is constituted of steel-tubing units welded-up in jigs and reinforced by tension-wires. The question of fuselage design is dominated by the need of an accessible powerplant mounting. In the present stage of aircraft-engine development it is necessary to overhaul the engine rather frequently, that is, every 200 to 300 hr. at least, and it is therefore important to be able to remove it in a minimum length of time so as not to tie up the plane for an undue period. In fact, the ideal scheme seems to be to have a spare powerplant available at all times for substitution. The steel fuselage lends itself particularly well to the accomplishment of this very desirable feature of accessibility and this can be carried out in a cleancut manner by extending the upper and lower longerons on each side so as to meet at the front of the engine support. In the older forms of veneer-covered-truss fuselages or with the so-called monocoque construction the engine was generally extremely inaccessible, at any rate from both sides.

Regarding the general cabin design for the passenger compartment the requirements in the matter of comfort, good vision and ventilation seem obvious. Later we may expect to see serious consideration given to attempting great structural strength in the cabin structure to protect the passengers as much as possible in case of a crash. This would follow the precedent set in railway Pullman-car construction but, of course, the problem in the case of aircraft is rendered far more difficult by minimum-weight requirements. Easy access to the cabin from the ground is naturally desirable from the passenger's standpoint and in most enclosed designs this has been carefully studied.

There is apparently considerable difficulty in arriving at the best location for the pilot. The first requirement is, of course, the best possible vision not only for landing but also while in the air; the pilot should be able to see in all directions. In the event of the plane nosing over, the pilot should be in such a position as to be protected from the engine, gasoline tanks or other heavy units. It is undoubtedly desirable, although not essential, that the pilot be able to obtain access to the passengers' compartment, and there should be also accommodation for a mechanic or relief pilot. The pilot's cockpit should be in such a place as to simplify both the plane and the engine controls, making them as direct as possible. Of course, in the case of a multi-engine plane in which the engines are carried out on the wings a suitable position for the pilot is readily found in the forward part of the fuselage, but with the single-engine plane some other location must be found. In a very recent design the pilot is placed alongside of the engine; this appears to have some advantages.

I have not considered the tail-skid or landing-gear separately but these very important elements of the design need much study and development to reduce the present high cost of upkeep. There appears to be a

definite need for some shock-absorbing means in both the landing-gear and the tail-skid. By shock-absorber I mean a device to actually absorb the shock and not store it momentarily as is done with springs or elastic rubber suspensions.

The location of the gasoline tanks is another problem that has not reached a final solution, in my estimation. There are several factors to be taken into consideration, such as the method of gasoline feed, that is, pressure or gravity, the capacity of the tanks, and effect of the full or empty tank on the respective balance of the airplane, remoteness from any fire-producing element and accessibility for filling. The most important consideration of all is undoubtedly that of fire prevention and on this score a location out on the wings is preferable.

Scanning the question of the powerplant for a typical commercial airplane, the first requirements we encounter are reliability and accessibility. Next in order come economy in operation and low initial cost. In the matter of reliability of the engine itself, a high state of development has been reached, although the powerplant as a whole has not advanced in a corresponding degree due to the lack of coordination of engine and plane design and the incomplete working out of important installation details. This handicap is being overcome rapidly as engine designers become more familiar with actual airplane operating conditions and plane designers appreciate more and more the installation and operating requirements of the powerplant. Basically, then, we find that there exist several well-known makes of engine that are highly reliable. The next step is to produce reliable engines that will lend themselves to simple installation and easy maintenance. This phase of the situation is well understood by all airplane-engine designers, as is shown by some typical examples of modern powerplants referred to later. It should of course be borne in mind that the engine designer must lead the way, since the plane must be built around the engine to form an harmonious combination. The problem therefore requires the closest possible cooperation between the engine and the plane designer. Both should acquire extensive flying experience to obtain the best possible insight into operation and maintenance problems.

Powerplant Requirements

Carburetion is undoubtedly the foremost of the concrete examples of powerplant requirements, since the location of the carbureter has considerable influence on the design of the engine and affects the design of the plane. The ideal gasoline system seems to be gravity-feed, owing to its inherent simplicity and consequent reliability. Assuming a fairly high location for the gasoline tanks, it is easy by placing the carbureter beneath the engine to obtain a very efficient gravity feed with ample head under all normal flying conditions. There are several other advantages in thus locating the carbureter, including the ability to carry the air-intake out through the lower cowling, eliminating any possible danger of fire due to engine backfiring. It is, of course, important to carry gasoline-overflow pipes or vent connections into the air-intake so that in case of flooding the gasoline will drip harmlessly from the air-intake. It should be remembered that in the case of the conventional single-engined tractor powerplant installation the engine is most accessible from beneath or from either side, whereas in the case of the automobile engine the sides and top are easiest to work on.

Next after the carbureter comes the lubricating system in importance as regards accessibility requirements. This applies to such important elements as the oil-pump itself, pressure-regulating valve and oil-screen, all of which should be readily accessible in the completed plane. It appears to be good practice to operate the engine with a dry sump; in which case an external oil-tank, which serves also as an oil-cooler, must be provided in proximity to the engine.

The water-pump is usually driven from a vertical shaft at the rear end of the engine and can thus be easily inspected from underneath. The ignition system, which should invariably be supplied in duplicate whether it be in the form of magnetos or battery distributors, is best arranged at the rear end transversely with respect to the crankshaft so that adjustments or inspections can be made from either side. The location of the spark-plugs is more or less determined by the general type of engine construction, but one set at least should be readily accessible from either side; in the case of a V-engine the other set can be located conveniently in the V if there is plenty of space available. In this case a suitable sliding door should be provided in the upper part of the cowling so that these spark-plugs can be reached without removing the cowling as a whole.

The radiator should be considered as part of the powerplant, since its design is tied up with the characteristics of the particular engine employed. There are several alternative locations for the radiator, but the so-called "nose" radiator directly behind the propeller appears to have overwhelming advantages for commercial purposes. Although this is by no means the most efficient position for a radiator so far as its cooling ability is concerned, it appears that for convenience in connecting to the engine and for general accessibility it offers sufficient advantages to warrant its general adoption for commercial planes. The radiator should have ample area and a liberal expansion-tank, together with an efficient shutter equipment. It is important that the shutters fit well when closed; and it is preferable that they be balanced and streamlined so as to offer no difficulty in maintaining any desired adjustment in flight. Apparently it is good practice to mount the engine on wood bearers. These can be extended to carry a suitable stamping that in turn supports the radiator. These same timbers can also be extended through the engine firewall to support the gasoline tank if such a location is suitable.

There are a great many very important details in connection with the installation of the engine and its controls; these deserve the closest possible attention. Gasoline, water and oil lines must all be worked out with a view to their withstanding vibration, but at the same time the use of rubber hose for either water or oil connections should be limited as far as possible, suitable metallic linings being employed to prevent any possible obstruction by rubber particles disintegrated by the action of the gasoline or oil. Needless to say, in every case where rubber connections are used for gasoline or oil, strainers should be provided in a very accessible location on the engine side of the joint. Engine controls, such as spark, throttle, mixture and radiator-shutter, should all be carried out in a mechanical and workmanlike manner. The use of flexible cable for such work is not to be recommended. The construction should take the form of tubular connecting-rods combining lightness with rigidity, bell-cranks and levers connected with suitable clevises, and the proper number of bearings suitably arranged to carry the various shafts with the least cramping tendency. It is desirable to carry out a mechanical, positive construction such as that outlined above in all the flying controls; that is, in an ideal system no flexible cable

would be used for operating ailerons, rudder, elevator or adjustable stabilizer if used. The propeller also can be considered an important part of the powerplant since in its design the characteristics of the engine must be taken into consideration, although the airplane itself exerts a considerable influence on the propeller design.

The question of starting means for airplane engines has been frequently discussed, with various results. The electric starter is apparently the only available successful mechanical starter attached to the engine. Its use, naturally, necessitates the employment of a storage battery. The battery involves some objections from the standpoints of maintenance, weight and injury to metals or wood in its vicinity. All things considered, the use of a mechanical engine starter on a commercial airplane is open to question, since with suitable priming devices, handcrank magneto, etc., the engine can be started very readily by hand. Experience alone will show whether the advantages of the electric starter are sufficient to overcome such disadvantages as I have cited.

I have purposely refrained from discussing air-cooled engines or other types of powerplant, since the purpose of this paper is not so much to point out future possibilities as to present the status of commercial aviation today, placing particular stress on retarding influences. I believe, in general, that there are several types of modern high-grade power-plant from which to choose and that the lack of a suitable powerplant cannot be said to be obstructing the advance of commercial aviation, although I look forward to constant improvement of the engines in the direction of greater reliability and economy and decreased cost of construction with not very much reduction in weight.

Essentials of Air Transportation

Having considered the question of commercial aviation from different angles, we are in a position to specify some of the more important steps necessary in the further development of air transportation. As I have stated, this paper is necessarily too limited in scope to include a discussion of a multitude of detail refinements, each of which will contribute its quota to commercial aeronautics. I might cite navigating instruments, which are the basis of a large field for development, and wireless direction-finding, wireless telephone and night-flying equipment. There is great need for propellers of moderate cost that will withstand the attacks of rain or sleet; variable-pitch and reversible propellers are gradually being evolved from the experimental stage. Considerable work is being done on wings having variable camber or variable surface. These few examples of development activities in the various branches of airplane design indicate the ramifications of the art and the hopelessness of attempting to present a complete picture of the situation. I have tried to pick the high lights and draw some general conclusions from them.

Summing up, I have enumerated the following four points which may be said to represent the essential and fundamental requirements for the further progress of commercial aviation:

(1) A system of landing-fields must be determined upon and put into service throughout the country as rapidly as possible. Although at the outset air traffic will be extremely limited, unless these landing-fields are available in advance, I can see no hope for the rapid extension of commercial air-transportation. I am glad to note that the daily press is giving its support to the movement to construct municipal landing-fields throughout the country.

(2) The aid of Government experimental stations should be enlisted in the task of eliminating so far as possible such danger factors as are inherent in the present airplane designs. I have in mind chiefly the matter of stalling which is referred to at considerable length above. A partial solution of this problem may lie in having an intermediate stop for each set of flying controls, that would allow sufficient range for normal flying, although perhaps not sufficient just previous to landing or when taxiing. A Federal system of inspection, coupled with suitable short-period licenses and stringent regulations governing important elements of aircraft design, would undoubtedly assist in preventing a certain percentage of avoidable accidents.

(3) Government patronage of air-transportation companies in the form of mail contracts, which might be made somewhat more liberal than the present ones by charging a very nominal extra postage. I am fully aware that at the outset of the Air Mail Service this procedure was not successful in attracting patronage, but I believe this was due to an excessive surcharge. A preferable course might be to limit the weight to one-half that allowed by rail route for the same postage. I have touched upon the possibility of establishing Government franchises over specific air-routes. While I recognize the crudity of the suggestion, some means might be devised of restricting the number of Federal licenses to be issued to air-transportation companies to operate between any two points for a definite period. Such licenses could have qualifying clauses stipulating a minimum number of trips or in some other way insure adequate service.

(4) Both plane and engine development along utilitarian lines should be concentrated on by our Government experimental stations. In the final analysis, even in time of war, reliability and ease of maintenance are important factors. In the past we have been paying almost exclusive attention to the performance of our military planes, which was, of course, a laudable endeavor. Nevertheless, it appears to be equally important to encourage development work that would be more applicable to peacetime flying, recognizing that the fruit of this would be extremely valuable in the evolution of commercial aeronautics, which in turn would help build up what would be in effect a Reserve Air Force. In other words, neither extremely high speed nor rapid climbing to excessive altitudes represents characteristics of particular value to commercial air-transportation, whereas increased economy in operation, slower depreciation and decreased upkeep expense are all vital factors in this connection.

Viscosity and Friction

By Winslow H. Herschel[1]

Annual Meeting Paper *Illustrated with* Charts

THE author divides the study of lubrication into different regimes in which different properties of the lubricant have the controlling influence and discusses at length viscosity effect in the complete-film-lubrication regime, including comment on the properties of lubricants, units for viscosity measurement, absolute viscosity relation to the readings of instruments ordinarily used and mathematical analysis, with reference to data that are presented in tabular and chart form.

Viscosity estimation at one temperature from the observed viscosity at another temperature is then treated in a somewhat similar manner, inclusive of discussion bearing on complete film lubrication, as are the subjects of journal friction and viscosity in which the mathematical analysis is continued, and friction tests are described briefly, copious specific references being given.

Consideration is given to the transition point, the relation between the different factors at the transition point and incomplete film lubrication and the oiliness of lubricating oils, the last including a description of Bureau of Standards tests.

A lengthy discussion of the differences in oiliness of different lubricants shown by laboratory and service tests follows, many references to tests and testing machines being cited and quotations made from reports.

Ten specific desirable features of oil-friction testing-machines are enumerated and commented upon in the light of previous experiences that are cited, and nine specific conclusions regarding viscosity and friction are stated.

THE study of lubrication is made more difficult by the fact that there are different regimes in which different properties of the lubricant have the controlling influence. At the highest speeds and lowest pressures the friction is nearly constant under widely varying conditions. At lower speeds the viscosity of the lubricant and the kind of material constituting the rubbing surfaces have a marked effect; and at the lowest speeds and highest pressures another property of the lubricant, which can be called oiliness, has the predominant influence. Frequently, only two regimes are considered; that of complete film lubrication where the viscosity has the greatest effect, and that of incomplete film lubrication where the oiliness becomes of major importance. The transition point, where the friction is at a minimum, comes within the former regime. The influence of bearing metals is evident with incomplete film lubrication, and in the greater part of the regime of complete film lubrication.

In selecting a lubricant the properties that need to be considered can be divided into two classes; properties indicating that it is suitable for the purpose at hand, and those giving assurance that it will be reasonably lasting in use. It is not the purpose of this paper to consider the question of the deterioration of oils, but merely the above-mentioned properties of new oils that indicate suitability at least for short-time use. If all the changes of the lubricant with time, by evaporation, oxidation or otherwise are disregarded, the only remaining properties that determine the friction are viscosity and oiliness.

TABLE 1—UNITS OF VISCOSITY

1 dyne-sec. per sq. cm.	=1 poise
1 lb-min. per sq. in.	=4.137 x 10^6 poises
1 kg-sec. per sq. meter	=98.07 poises
1 poundal-sec. per sq. in.	=2,143 poises

Viscosity Effect in the Complete-Film-Lubrication Regime

The instrument most generally used for determining the viscosity of lubricating oils by oil refiners in the United States is the Saybolt universal viscosimeter.[2] Its adoption, together with the standard temperatures of 100, 130 and 210 deg. fahr. (37.8, 54.4 and 98.9 deg. cent.), reduced the confusion and inaccuracy resulting from the use of viscosimeters of various types at different temperatures. Although conversions can be made from one instrument to another, there is no general agreement in regard to the conversion factors.

When a comparison is made between viscosity and friction it is necessary to express viscosity in some unit that is independent of the instrument used for measuring the viscosity, and equals or is proportional to the true or absolute viscosity. With the Saybolt instrument results are expressed in seconds, a unit that does not fulfill this requirement, although absolute viscosity can be calculated from Saybolt seconds by using a suitable equation.

The unit of absolute viscosity has been defined as the force that will move a unit area of plane surface at a unit speed relative to another parallel plane surface from which it is separated by a layer of the liquid of unit thickness. Most published data on viscosities of liquids are expressed in the centimeter-gram-second unit of absolute viscosity, known as the poise, and it will therefore be used in this paper. Table 1 is convenient for

TABLE 2—LIQUIDS AND TEMPERATURES NECESSARY TO GIVE CERTAIN ABSOLUTE VISCOSITIES

Viscosity, poises	Liquid	Approximate Temperature, deg. fahr.	deg. cent.
0.01	Water	68	20
0.05	Sucrose, 60 per cent	182	83
0.10	Sperm Oil	135	57
0.20	Sperm Oil	94	34
0.30	Olive Oil	112	44
0.40	Olive Oil	98	37
0.50	Olive Oil	87	31
0.75	Olive Oil	71	22
1.00	Olive Oil	60	16
5.00	Castor Oil	83	28
10.00	Castor Oil	68	20

[1] Associate physicist, Bureau of Standards, City of Washington.

[2] See Standards adopted in 1920 by the American Society for Testing Materials, p. 104; also, Tests and Testing Standards adopted by the National Petroleum Association, Sept. 22, 1920; also, Bureau of Mines Bulletin No. 5, containing the Report of Committee on Standardization of Petroleum Specifications, p. 28.

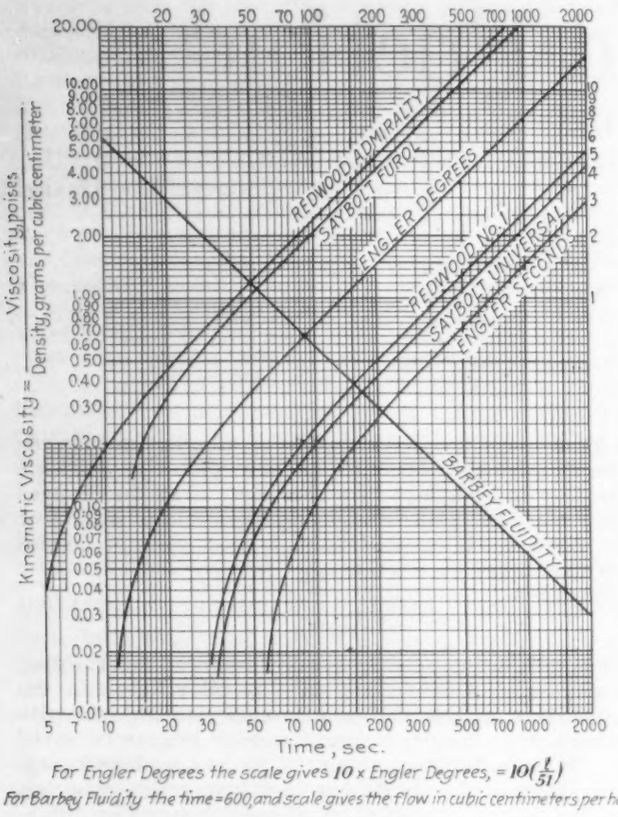

Kinematic Viscosity = Viscosity, poises / Density, grams per cubic centimeter
Time, sec.
REDWOOD ADMIRALTY
SAYBOLT FUROL
ENGLER DEGREES
REDWOOD NO. 1
SAYBOLT UNIVERSAL
ENGLER SECONDS
BARBEY FLUIDITY
For Engler Degrees the scale gives 10 x Engler Degrees, = 10(t/51)
For Barbey Fluidity the time = 600, and scale gives the flow in cubic centimeters per hour

FIG. 1—CONVERSION DIAGRAM FOR VISCOSIMETER READINGS

comparison between different units that are sometimes encountered, while Table 2 has been compiled to give a concrete meaning to viscosities expressed in poises.

ABSOLUTE VISCOSITY RELATION TO THE READINGS OF INSTRUMENTS ORDINARILY USED

The Saybolt universal viscosimeter and most of the other commercial viscosimeters that are used with lubricating oils are of the efflux type and, if there is no turbulence, their readings can be converted into poises by the equation

$$V_k = At - (B/t) \qquad (1)$$

where

A = an instrumental constant
B = an instrumental constant
V_k = kinematic viscosity which is the quotient obtained by dividing the viscosity in poises by the density in grams per cubic centimeter
t = time of flow in seconds

The term in parenthesis in equation (1) is the kinetic energy correction

$$B/t = (Q\,m) \div (8\,\pi\,L\,t) \qquad (2)$$

where

B = an instrumental constant
L = effective length of the outlet tube, usually slightly in excess of the measured length; the difference is known as the Couette correction
m = a coefficient approximately equal to unity
Q = volume of flow in cubic centimeters in the time t
t = time of flow in seconds

If the flow is so slow that B/t is negligible in comparison with At, and the outlet tube is so long that the Couette correction can be neglected, then the viscosity can be calculated from the equation

$$V_k = At = (\pi\,g\,d^4\,Ht) \div (128\,Q\,L) \qquad (3)$$

where

A = an instrumental constant
d = diameter of the outlet tube
g = acceleration of gravity, or 981 cm. per sec. squared
H = average hydrostatic head above the bottom of the outlet tube, producing flow
L = effective length of the outlet tube
Q = volume of flow in the time t
t = time of flow in seconds
V_k = kinematic viscosity

Equation (3) does not apply to commercial viscosimeters, with the probable exception of the Barbey, because the outlet tubes are too short. On this account, and because the Couette and kinetic-energy corrections cannot be calculated on theoretical grounds, it is necessary to determine values of L and m, and hence of A and B, in equation (1), by the use of calibrating liquids of known viscosity. The viscosity of these liquids is measured by some suitable viscosimeter to which equation (3) applies. If L and m are determined in this way, the greatest error will be due to inaccuracy in the measurement of d.

Early investigators assumed that there would be no turbulence and equation (1) would apply, provided the value of K in equation (4) was less than 2000.

$$K = 4\,Q \div (\pi\,d\,t\,V_k) = v\,d/V_k \qquad (4)$$

where

d = diameter of outlet tube
K = a constant
Q = volume of flow in time t
t = time of flow in seconds
v = velocity of flow in centimeters per second
V_k = kinematic viscosity

While it is now known that K decreases with the length of outlet tube, the law of variation is not known. K has a value of 800 for the Saybolt universal viscosimeter, and therefore water cannot be used as a calibrating liquid for that instrument. This is unfortunate, because water is easily procurable and its viscosity is more accurately known than that of any other liquid. Values of A and B will vary with each individual instrument on account of unavoidable variations in dimensions. If, however, these constants are determined for a type of instrument for which standard dimensions with suitable tolerances have been adopted, the variations in the constants will not exceed a reasonable predetermined amount.

In making conversions between different types of viscosimeters it is convenient to write equation (1) in the form

$$t = C\,V_k(1 + \sqrt{[1 + (D/V_k^2)]}) \qquad (5)$$

where

$$C = 1 \div 2\,A$$
$$D = 4\,A\,B$$

The best available values of A, B, C and D are given in Table 3, for viscosimeters of normal or average

TABLE 3—INSTRUMENTAL CONSTANTS FOR VISCOSIMETERS

Instrument	A	B	C	D	Minimum Time, sec.
Saybolt Universal	0.0022000	1.800	227.30	0.01584	32
Saybolt Furol	0.0220000	2.030	22.73	0.17860	13
Engler	0.0014700	3.740	340.30	0.02196	56
Redwood No. 1	0.0026000	1.880	192.30	0.01952	30
Redwood No. 2(Admiralty)	0.0239000	0.403	20.92	0.03857	5
Ubbelohde	0.0000868	1.440	57.60	0.04993	155

standard dimensions, together with the minimum time of flow to which the equations apply.

Table 3 has been used to calculate Fig. 1, the form of which is due to MacCoull[3] who, however, extended his curves to lower times of flow. With all except the Engler and Barbey viscosimeters, the results are usually reported in seconds. With the Engler viscosimeter, results are usually reported in Engler degrees, the values being obtained by dividing the time of flow by the water rate, or the time of flow for water at 68 deg. fahr. (20 deg. cent.), which varies from 50 to 52 sec. Since the viscosity is not proportional to the time of flow, a value in Engler degrees, which is only the ratio between times of flow, does not represent the ratio of the viscosity of the liquid tested to the viscosity of water. With the Barbey instrument, tests are run for 10 min. and results are reported as "fluidity," which is the flow in cubic centimeters per hour.

Viscosity Estimation at One Temperature from Observed Viscosity at Another Temperature

It is known that oils grow less viscous or "thin out" as the temperature increases, but the exact law of variation is unknown. If it is desired to estimate the viscosity of an oil at one temperature from the observed viscosity at another, a convenient method is to assume that the logarithmic viscosity-temperature graphs are straight and meet at a point. This assumption is sufficiently accurate for most practical purposes if the fahrenheit scale is used, and if fatty oils, steam-cylinder oils, oils of lower viscosity than spindle oils and imperfectly refined oils such as fuel oils, are excluded. It is also necessary that all oils on a diagram should be from one crude, as different crudes show different points of intersection.

Fig. 2 shows such a logarithmic viscosity-temperature diagram as has been referred to, from tests on different fractions of the same naphthene-base oil. It will be seen that, within the limits of accuracy of viscosity determinations, these oils give straight graphs and, since they are all of the same base, the graphs within a certain range of viscosity meet at a point. The point of intersection for oils of any other crude could be obtained in a similar manner, but if more accurate information is not available, the points of intersection can be assumed as given in Table 4.

TABLE 4—POINTS OF INTERSECTION OF LOGARITHMIC VISCOSITY-TEMPERATURE GRAPHS

Base of Crude Oil	Viscosity, poises	Temperature deg. fahr.
Paraffin	0.0038	589
Naphthene	0.0076	371

None of the tests used in finding the values given in Table 4 were run at temperatures over 212 deg. fahr. (100 deg. cent.) or below 60 deg. fahr. (15.6 deg. cent.), and extrapolation beyond these limits would of course be hazardous.

In estimating viscosities, one point on the diagram is located by the known viscosity of the oil in question at a given temperature. The point of intersection is then located and the desired viscosity is read from the straight line connecting these two points. By combining the methods of converting from readings of one viscosimeter to another, and of estimating the change of viscosity with the temperature, conversions can be made from one type of instrument at one temperature to another type at another temperature, although Fig. 1, alone, serves merely for comparisons between tests at the same temperature. But estimates of the change of viscosity with the temperature must always be dangerous, as impurities may be present in the oil and change the temperature coefficient of the viscosity.

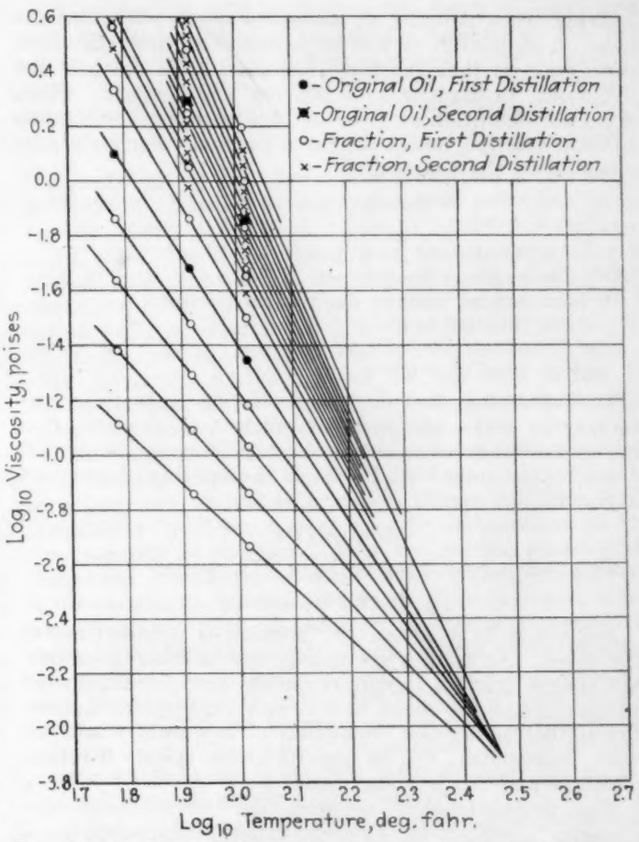


FIG. 2—LOGARITHM VISCOSITY-TEMPERATURE DIAGRAM BASED ON TESTS OF DIFFERENT FRACTIONS OF THE SAME NAPHTHENE-BASE OIL

When it is desired to know the viscosity of an oil at the temperature of a bearing, as in friction tests, the viscosity determinations should be made at several temperatures within the range of the probable bearing temperature. The logarithmic viscosity-temperature diagram, together with the point of intersection, can then be used as a check on the accuracy of the viscosity determinations, and as a means of enabling the interpolation to be made on a straight rather than on a curved line.

Every mathematical treatment of the subject of lubrication is based upon the assumption that viscosity is the only property of the lubricant that has an influence upon the friction, and that the degree of smoothness or the material of the bearing and the journal are also without influence. While many friction tests have been made and published, there are very few that give sufficient data to check the accuracy of proposed formulas. All experimenters have observed the pressure, the speed and the coefficient of friction, but few have paid attention to measurements of the viscosity and of the clearance in the bearing, which are equally important. Reference[4] is made to some of the few cases where film thickness has been measured.

It is known that a journal is not concentric with the

[3] See *Lubrication*, May, 1921.

[4] See *Transactions of American Society of Mechanical Engineers*, vol. 27, p. 423; *Archiv für Electrotechnik*, vol. 8, p. 364; and *Journal of the American Society of Mechanical Engineers*, vol. 39, p. 320.

bearing when running at moderate speeds; but, for the sake of simplicity, it will be assumed at first that it is concentric so that the film thickness, Δ, is one-half the difference in diameters of bearing and journal. Then, from the definition of viscosity, the turning moment due to fluid friction would be, for a journal completely surrounded by the bearing,

$$M = [\mu d (\pi d l) V] \div 2\Delta \qquad (6)$$

where

d = diameter of the journal
l = length of the journal
M = turning moment due to fluid friction
μ = viscosity in poises
$\pi d l$ = area of the rubbing surfaces
V = speed of rubbing

In expressing the results of friction tests it is customary to make use of the coefficient of friction, f, a purely arbitrary value obtained by dividing the tangential force by the total load P. Thus the turning moment of a journal having a diameter of d is

$$M = \tfrac{1}{2} f d P \qquad (7)$$

Combining equations (6) and (7), we get

$$f = [\mu (\pi d l) V] \div \Delta P \qquad (8)$$

According to equation (8) friction is proportional to the speed. At certain low speeds this is true,[5] at moderate speeds friction is approximately proportional to the square root of the speed, and at very high speeds Lasche[6] found that under the conditions of his tests f was almost independent of the pressure, the speed, the temperature and the bearing metal.

The proportionality between the friction and the viscosity is shown by Tower's[7] experiments, made on a bearing which extended about one-half way around the journal. In tests with lard oil at various temperatures, the highest friction was obtained at 60 deg. fahr. (15.6 deg. cent.). Calling the friction and viscosity 100 at this temperature, Table 5, calculated from Tower's data, shows the relative values of the coefficients of friction and of the viscosity of lard oil at the other temperatures.

It will be seen that there is a considerable variation in the change of viscosity with the temperature, according to different experimenters, probably due in part to differences in the viscosimeters employed. While the change of friction with the temperature is not exactly the same at all speeds, the average values for friction lie between those of Goodman and the Bureau of Standards for viscosity. Thus, as indicated by equation (8), at least under certain conditions, friction is proportional to viscosity. That friction is inversely proportional to the film thickness has been shown by Heimann.[8]

There is nothing in equation (8) to indicate that f would not continue indefinitely to decrease as the pressure increased but, in reality, there is a change in the regime at very high pressures or very low speeds at what is called the transition point; this is considered later. Thurston's[9] tests with varying pressure gave indications not only of a transition point but also of the influence upon friction of a change in the material of the rubbing surfaces. He found that the coefficient of friction was less at a pressure of 500 lb. per sq. in. (35.0 kg. per sq. cm.) than for either 250 or 750 lb. per sq. in. (17.5 or 52.5 kg. per sq. cm.), and less for steel journals in brass bearings than for cast-iron journals in steel bearings. It is evident that these results cannot be explained by equation (8).

Friction Testing of Bearing Metals

It appears from the results of Thurston and others that, under certain conditions, a friction machine can be used to determine the relative friction-reducing properties of different alloys. As the effect of different bearing metals upon the friction can be noted above as well as below the transition point, some friction tests of these metals will be considered briefly at this point.

G. H. Clamer,[10] who used a Cornell friction machine, observed the friction, the running temperature and the loss of metal by wear, obtained by weighing the bearing metal before and after test. To get sufficient wear he ran each test at a speed of 525 r.p.m. for 10,000 revolutions, or about 3 hr. Neither the rise in the temperature nor the wear shows any regular relation to the friction. With a friction of 13.0 to 18.5 lb. (5.9 to 8.4 kg.) and with a pressure of 1000 lb. per sq. in. (70.3 kg. per sq. cm.), as stated by Clamer, and assuming one test-bar, it can be calculated that the load on the bar was 1750 lb. (794 kg.) and that the coefficient of friction varied from 0.00743 to 0.01057. The Cornell machine was at one time built to hold two test-bars, but Clamer does not state his area of rubbing surface, so that the number of test-bars is uncertain.

While Clamer's method of measuring wear is perhaps a usual one, there is no satisfactory method according to Goodman.[11] After having tried measuring the thickness by a Whitworth measuring machine, weighing the bearing in a chemical balance and measuring with a spherometer, arranging the legs on portions of the bearing not exposed to wear, he concludes

> All the methods failed to show any appreciable wear after a month's run under a pressure of 500 lb. per sq. in. (35.1 kg. per sq. cm.). These tests were made of course after the bearing was properly bedded down

If Goodman's statement is accepted as applying to Clamer's work, the conclusion is inevitable that the wear noted by Clamer was due to inaccuracy in the fit of bearing and journal, and that the wear had no significance except perhaps as an indication of the ease or difficulty with which a given bearing metal can be fitted to the journal. Goodman states that it would take a month or more to secure a perfect surface by wear, and that he loaded the bearing just beyond the elastic limit of the metal to expedite matters, and left this load on for about 15 min. Even after this treatment, a week's run in the testing machine was necessary before he considered the bearing had bedded itself perfectly. If preparation of this kind is necessary, it is small wonder that other experimenters have noted considerable wear of bearings. It might be objected that the quality of the bearing metal was changed so that Goodman's tests do not show the friction quality of his original samples. While it thus remains a problem in testing bearing metals how to make a perfect fit by other means, the above objection would not apply to tests of lubricants.

The Transition Point

It has been pointed out previously that equation (8) gives no indication of more than one regime of lubrication, or of the change at the transition point, in the rela-

[5] See *Zeitschrift des Vereines Deutscher Ingenieure*, vol. 46, p. 1890.

[6] See *Zeitschrift des Vereines Deutscher Ingenieure*, vol. 46, p. 1346; *Journal of the American Society of Naval Engineers*, vol. 11, No. 2; and *Zeitschrift für Mathematik und Physik*, vol. 50, p. 97.

[7] See *Proceedings of the Institution of Mechanical Engineers*, 1883, p. 651.

[8] See *Zeitschrift des Vereines Deutscher Ingenieure*, vol. 49, p. 1165.

[9] See Friction and Lost Work, by R. H. Thurston, p. 297.

[10] See *Journal of the Franklin Institute*, vol. 156, pp. 61 and 70.

[11] See *Proceedings of the Institution of Civil Engineers*, vol. 189, part 3, p. 128.

tion between the different factors that determine the friction. Yet that such a change does occur has been shown both by experiment and by calculations based upon the laws of hydrodynamics.

Sommerfeld made a very thorough investigation of the hydrodynamics of the lubrication of a journal completely surrounded by the bearing. There are too few tests available with sufficiently complete data to check his formulas in all details, but certain points are in agreement with the tests. His equation for lubrication above the transition point approaches equation (8) as the speed increases and the journal becomes more and more nearly concentric with the bearing. Below the transition point, the friction increases as the speed decreases; so, the transition point is the point of minimum friction. Sommerfeld gives a theoretical equation for conditions at the transition point which can be written

$$\mu = (50\, p/\pi^2 n) \times (\Delta/d)^2 \qquad (9)$$

where

d = diameter of the journal
l = length of the journal
μ = viscosity in poises
n = speed of the journal in revolutions per minute
p = pressure on the bearing

Viscosities are usually given in poises, or in times of flow from which the viscosity in poises can be calculated by the equations already given. If the viscosity is expressed in poises, p must be taken in dynes per square centimeter, or 69,000 times the pressure in pounds per square inch but d and Δ can be taken in any convenient unit. If p is known in pounds per square inch, it might be convenient to use the equation,

$$\mu = (350{,}000\, p/n) \times (\Delta/d)^2 \qquad (10)$$

where

d = diameter of the journal
Δ = thickness of lubricating film
μ = viscosity in poises
n = speed of the journal in revolutions per minute
p = pressure on the bearing

The tests of Stribeck show that, with a given viscosity, the ratio p/n is a constant in accordance with equation (9). Using a viscosity of 1.90 poise, calculated from his data and the constants of Table 3 for the Engler viscosimeter, the clearance as calculated from equation (9) would be 0.0117 cm. (0.0046 in.). This is roughly checked by Sommerfeld's[12] value of 0.0130 cm. (0.0051 in.), presumably calculated from a different viscosity obtained by the incorrect equation of Ubbelohde for the Engler viscosimeter. Sommerfeld also obtains a value of 0.020 cm. (0.0079 in.) from the tests of Biel[13] and remarks that, although the actual clearances are not known, they were doubtless of the same order of magnitude. From the above value of 0.0117 cm. (0.0046 in.) from Stribeck's tests, and Sommerfeld's equation

$$f = 1.886\, \Delta/d \qquad (11)$$

the coefficient of friction at the transition point would be 0.00306. This is in fair agreement with Stribeck's experimentally determined values of 0.0035 to 0.0039.

To show the very low viscosities theoretically required with light loads, high speeds and small clearances, equation (9) has been applied to the case of a steam turbine, assuming a pressure of 80 lb. per sq. in. (5.62 kg. per sq. cm.), a speed of 1800 r.p.m., and a ratio of $\Delta/d = 0.0005$. Then the viscosity would be 0.00389 poises, which is about that of water at the running temperature of turbine bearings.

The difference between the calculated viscosity and that actually employed does not indicate an error in the equation, nor mistaken practice. There is always the possibility that the pressure and temperature in the bearing will be increased above the normal values from imperfect alignment or other cause, thus necessitating a more viscous lubricant. The friction increases much more rapidly with a decrease of viscosity below the transition point than with an increase in viscosity above it; so, it is impracticable actually to use a lubricant having the viscosity of minimum friction at the nominal temperature of the bearing and higher viscosities are always used. The excess friction above that at the transition point is the price that must be paid for an adequate factor of safety against seizure.

Some evidence of the general correctness of Sommerfeld's equations is furnished by his report on the examination of 40 locomotives that always ran in the same direction. According to the older theory of Thurston, the point of nearest approach of the bearing and the journal, or point of greatest wear due to fluid friction, would be toward the "on" side from the line of pressure; that is, around the journal in a direction opposite to the direction of rotation. According to Sommerfeld, the point of greatest wear should be on the other side of the line of pressure. It is therefore of interest that of the 40 locomotives, 30 showed more wear on the "off" side of bearings, 7 showed more wear on the "on" side and 3 were doubtful. While a majority of the locomotives showed wear in accordance with Sommerfeld's calculations, it is doubtful whether the 10 exceptions indicate that there was incomplete film lubrication in those cases,

[12] See *Zeitschrift für Technische Physik*, 1921, p. 598.

[13] See *Zeitschrift des Vereines Deutscher Ingenieure*, vol. 64, pp. 447 and 483.

TABLE 5—COMPARISON OF RELATIVE FRICTION WITH RELATIVE VISCOSITY; FROM DATA OF TOWER AND OTHERS

Temperature		Relative Friction, according to Tower, for Speeds of									Relative Viscosity according to		
deg. fahr.	deg. cent.	Ft. per min. Meters per sec.	105 0.53	157 0.80	209 1.06	262 1.33	314 1.60	366 1.86	419 2.13	471 2.39	Goodman[14]	Thurston[15]	Bureau of Standards[16]
120	48.9		41	35	34	34	34	34	34	35	39	23	27
110	43.3		44	38	38	37	38	39	40	41	45	28	32
100	37.8		49	44	44	43	45	46	48	49	54	33	38
90	32.2		58	51	51	50	53	55	57	64	62	43	47
80	26.7		68	62	61	61	64	66	69	72	73	55	59
70	21.1		81	77	78	77	79	82	84	85	84	71	76
60	15.6		100	100	100	100	100	100	100	100	100	100	100

[14] See Lubrication and Lubricants, by L. Archbutt and R. M. Deeley, p. 85.

[15] See Friction and Lost Work, by R. H. Thurston, p. 191.

[16] From tests with the Bingham viscosimeter which is described in Bureau of Standards Scientific Paper No. 298.

that there were some factors that Sommerfeld did not take into account or that there were errors in the observations of wear.

It is interesting to observe that Sommerfeld's equations indicate an increase in the friction at lower viscosities than at the transition point, without any assumption of metallic contact or of incomplete film lubrication. But hydrodynamic theory accounts for an increase of friction of only 6 per cent, while the actual increase is very much greater. Sommerfeld's equations are based on the assumption that the clearance space is entirely filled with the lubricant, a condition that he has shown does not exist at very low speeds. His equations are therefore not in error, but are inapplicable to the regime of incomplete film lubrication. The conclusions are that, with complete film lubrication, experiments agree with theory within the experimental error so far as the properties of the lubricant are concerned; but, with incomplete film lubrication, theory is of little help.

Incomplete Film Lubrication and the Oiliness of Lubricating Oils

With complete film lubrication, viscosity is the only property of the lubricant that needs to be considered. With incomplete film lubrication, the differences in friction with different lubricants under otherwise identical conditions cannot be accounted for by differences in viscosity. Therefore, it is necessary to consider some other property, or properties, of the lubricant. This property is only vaguely understood; it is not identified with any recognized physical or chemical constants and is known by a variety of names such as body, oiliness, greasiness and the like. I shall use the word oiliness and define it as the property that causes a difference in the friction when two lubricants of the same viscosity at the temperature of the oil film are used under identical conditions.

A long series of tests was made at the Bureau of Standards to determine the utility of a certain friction-testing machine for measuring the oiliness of lubricants. The machine is of a well known commercial type and was belt-driven. The load is applied by a spring to a bearing block above the horizontal journal, the friction between the block and the journal being weighed by a lever arm having a sliding weight. The journal has a diameter of 3.748 in. (9.500 cm.) and is 3.480 in. (8.840 cm.) long. The width of the bronze bearing block is 2.010 in. (5.100 cm.) so that the gross projected area of the rubbing surface is 6.995 sq. in. (45.000 sq. cm.), thus checking the value of 7.000 sq. in. given in the manufacturer's circular. The maximum pressure ordinarily used was 715 lb. per sq. in. (50 kg. per sq. cm.), while the minimum attainable speed was 43.00 ft. per min. (0.22 meters per sec.). The arc of contact of the bronze bearing block was 65 deg., or less than one-half the arc of 163 deg. with which Tower obtained complete film lubrication on an otherwise somewhat similar machine. In all series of tests the bottom of the journal dipped into a cup of oil. To guard, if possible, against roughening of the journal when seizure took place, a special bearing block of white metal, consisting mainly of lead, was used. This block had neither oil-hole nor oil-grooves, and although the bronze bearing was thus supplied, the oil-hole was not used.

As the temperature could not be controlled, it was necessary to vary the viscosity by dilution. For the first series of tests, three oils were selected; a mineral oil of paraffin base, a second oil of naphthene base, and cottonseed oil. All three were diluted with 300-deg. mineral seal oil. This viscosity of minimum friction was about 0.05 poise, but with most of the tests the friction was practically independent of viscosity. On this account, it seems improbable that the condition of complete film lubrication was ever fully attained, although tests were made on both sides of the transition point. No comparison with Sommerfeld's equations is possible because the bearing did not completely surround the journal. Since the mineral seal oil had a viscosity near that of the minimum friction, kerosene and finally gasoline were used as diluents to obtain still lower viscosities. The excessive discordance in the readings that was observed in tests at these very low viscosities was doubtless due in part to the evaporation of the diluent and the consequent change of the viscosity during a test.

In the second series of tests, a mineral oil was selected as a standard of comparison and re-tests were made on this sample from time to time to detect changes in the smoothness of the rubbing surfaces. At the German Materialprüfungsamt, rape-seed oil is used for this purpose as is thus described by Holde[17]

> The machine is controlled now and then by using refined rape-seed oil. The coefficient of friction must come out within an error of 10 per cent under similar conditions of experiment; if this is not the case the machine must be run under an average pressure of 50 to 70 kg. per sq. cm. until the normal condition is reestablished; this sometimes requires several weeks.

The last two words show that there is need of some quicker method of obtaining a rubbing surface of standard smoothness.

Among the lubricants tested in the second series, already mentioned, were sucrose and glycerine solutions and petroleum oils containing mica and graphite, but there was no indication of differences in the oiliness. The tests also failed to show any superiority of the fatty oils as compared with mineral oils. While Meyers[18] also failed to find any advantage from the admixture of solid lubricants, it should be pointed out that the reduction of friction in case of failure of the oil supply, as shown by Mabery,[19] might be of considerable practical advantage. He found that a friction-testing machine would run much longer, after the supply of liquid lubricant had been cut off. if the oil had contained graphite.

In another series of tests at the Bureau of Standards, a comparison was made between the white-metal bearing used in all previous tests and the bronze bearing furnished with the testing machine, the lubricants being in general the same as in the second series. It was found that the coefficient of friction was mostly between 0.006 and 0.008 for the white metal and averaged about 0.009 for the bronze bearing. In most cases tests with the two bearings were alternated, so that the higher friction of the bronze bearing could not have been due to an increased roughness of the journal. The white metal had a higher carrying power than the bronze bearing; that is, an oil of lower viscosity could be used with the former without excessive friction or seizure. To determine whether the difference in friction and in bearing power between the two bearings was due to a difference in the curvature or of the film thickness, careful measurements were made of both bearings, but no difference could be detected. Taken all together, the tests of the Bureau of Standards appeared to show the impossibility of detect-

[17] See The Examination of Hydrocarbon Oils, by D. Holde, translated by E. Müeller, p. 124.

[18] See *Journal of the American Society of Naval Engineers*, vol. 29, p. 698.

[19] See *Journal of the American Society of Mechanical Engineers*, vol. 32, p. 163.

ing differences in the oiliness, unless the pressure was greater than about 800 lb. per sq. in. (56.2 kg. per sq. cm.) or the speed less than about 40 ft. per min. (0.20 meters per sec.).

Differences in Oiliness of Different Lubricants Shown by Tests

While the Bureau of Standards friction-machine tests above described and many others have failed to show differences in the oiliness, it has often been indicated by simple means that such differences exist. Archbutt and Deeley[20] suggest the following test to show that glycerine is deficient in oiliness.

> When a glass surface is rubbed by a wet finger, care having been taken to remove all grease, the friction between the skin and the glass is very considerable. Even such a thick liquid as glycerine, when the rubbing movement is slow, fails to keep the surfaces apart and prevent the glass from feeling harsh. On the other hand, a little grease, fat or lubricating oil will remain as a fairly thick film between the surfaces and enable them to slip freely over each other, even at low speeds.

Another simple means for testing oiliness is by using a lubricant as a cutting oil. Any machinist will use lard oil, when possible, to cut a "clean" thread, and it can be considered that the superiority of lard oil is due to oiliness. This is a case of intense pressure, as with gearing, and high pressures tend to produce incomplete film lubrication and manifestations of differences in oiliness.

J. H. Hyde of the National Physical Laboratory,[21] has made tests with a gear-testing machine designed by F. W. Lanchester and illustrated in the 1920 Report of the Lubricants and Lubrication Inquiry Committee of the British Department of Scientific and Industrial Research.[22] The machine is described in the National Physical Laboratory Report substantially as follows

> The machine consists of a worm-gearbox supported on ball bearings in such a way as to rotate about two axes, one at right angles to the worm shaft and the other at right angles to the driven shaft. The efficiency of the gear was measured directly by observing the angle of the axis about which the box tended to rotate. This enabled the efficiency to be obtained with one observation instead of calculating it from the energy supplied and transmitted in the usual way. Arrangements were provided on the machine for altering the load on the gear, and the drive was by a gasoline engine hand-governed for the particular speed required.

Referring to this machine in a discussion before the Physical Society, Stanton[23] said

> It was found that the frictional resistance of the gear was at 40 deg. cent. (104 deg. fahr.) the same with castor oil as with trotter oil, although the viscosities of the two were at that temperature as 6 to 1.

Reference is made also to full reports on tests with this machine in the *Proceedings of the Physical Society of London*[24] and other English publications. There is, however, danger of comparing the friction in tests in which the viscosities are so widely different, because it is difficult to determine how much of the difference in friction is due to a difference in viscosity, and how much to a difference in oiliness. Most of the tests showed a marked viscosity of minimum friction or of maximum efficiency. Arranged in order of excellence, based on this point of maximum efficiency, the oils tested were castor, sperm, trotter or neats foot, rape seed, F.F.F. cylinder, Victory Red and Bayonne, the last three being mineral oils.

TABLE 6—STATIC COEFFICIENTS OF FRICTION OF VARIOUS OILS

Name of Oil	Classification	Static Coefficient of Friction: Mild Steel on Cast Iron	Static Coefficient of Friction: Mild Steel on Lead Bronze
H. B., Clock	Mineral	0.271	0.275
Bayonne	Mineral	0.213	0.234
Typewriter	Mineral	0.211	0.294
Victory Red	Mineral	0.196	0.246
F. F. F. Cylinder	Mineral	0.193	0.236
Manchester Spindle	Mineral	0.183	0.262
Castor	Vegetable	0.183	0.159
Valvoline Cylinder	Compounded	0.143	....
Sperm	Animal	0.127	0.180
Trotter	Animal	0.123	0.152
Olive	Vegetable	0 119	0.196
Rape-Seed	Vegetable	0.119	0.136

R. M. Deeley made tests of static friction with a special machine of his own design, and found that the coefficient of friction is markedly less with fatty oils than with mineral oils of the same viscosity. His friction machine, which is illustrated[25] in the 1920 Report of the Lubricants and Lubrication Inquiry Committee of the British Department of Scientific and Industrial Research, is thus described

> The experiments were made with a small hand-driven machine. Three pegs, each 5/32 in. (4 mm.) in diameter, rested upon the flat surface of a disc of metal that could be rotated slowly. These pegs were secured, concentrically, to an upper disc that could be weighted as desired and actuated a spindle to which a spiral spring and recording finger were attached. When the lower disc was rotated, the pegs were carried with it by the friction until the surfaces slipped, owing to the stress on the spring, and the finger gave the value of the frictional resistance.

Table 6 gives the results of Deeley's tests. These apparently were made at room temperature.

The objection to Deeley's machine, as well as to gear machines, appears to be that the pressure cannot be measured because the area of contact is uncertain and apt to vary from wear. There is also no provision for controlling the temperature with this machine.

L. Archbutt in referring to his tests[26] with a Thurston

TABLE 7—EFFECT OF FATTY ACID UPON COEFFICIENT OF FRICTION

Test No.	Mineral Oil, per cent	Fatty Acid from Rape-Seed Oil, per cent	Coefficient of Friction
1	100.0	0.0	0.0066
2	99.5	0.5	0.0049
3	99.0	1.0	0.0045
4	98.0	2.0	0.0042
5	100.0	0.0	0.0066

[20] See Lubrication and Lubricants, by L. Archbutt and R. M. Deeley, p. 31.

[21] See Report of National Physical Laboratory for 1912, p. 100.

[22] See Report of the Lubricants and Lubrication Inquiry Committee, Department of Scientific and Industrial Research, London, for 1920, p. 50.

[23] See *Engineering*, vol. 108, pp. 755 and 758.

[24] See *Proceedings of the Physical Society of London*, vol. 32, part 2, p. 5S; and Report of the Lubricants and Lubrication Inquiry Committee, Department of Scientific and Industrial Research, London, for 1920, pp. 50 to 79.

[25] See Report of the Lubricants and Lubrication Inquiry Committee, Department of Scientific and Industrial Research, London, for 1920, p. 102.

[26] See *Journal of the Society of Chemical Industry* (London), vol. 39, pp. 51 to 60T.

machine has shown, in his discussion of the paper by Wells and Southcombe, that differences in oiliness can be shown by tests at moderate pressures, at slow speeds, without going to the extreme case of zero speed. The observations stated in Table 7 were made on a Thurston friction machine without stopping the machine, with a speed of 7 ft. per min. (0.0355 meters per sec.) and a pressure of 270 lb. per sq. in. (19 kg. per sq. cm.).

One of the objections frequently made to friction machines in general is that, when changing to a new oil, the effect of the one that preceded can be noticed for a long time. This may lead to erroneous conclusions. The difficulty in cleaning the rubbing surfaces is emphasized in an editorial in *Engineering*[27] in which, referring to Deeley, the statement is made,

> In his view a good lubricant forms a sort of quasi-chemical composition with metallic surfaces, and is with very great difficulty dislodged therefrom. In fact, to remove the oily film thus formed it is necessary to grind away the surface under water, it being impossible to wipe it clean and very difficult, perhaps impracticable, to dissolve it off.

Table 7 seems to refute this. It is believed possible that the idea of persisting films originated from noting that the friction did not change, as was expected, when the oil was changed; but this does not take into consideration the fact that, under certain conditions as in the Bureau of Standards tests, friction depends very slightly upon the kind of lubricant and can be changed only by a change in smoothness of the rubbing surfaces due to wear.

That fatty oils are superior to mineral oils when there is incomplete film lubrication, appears to have been proved unmistakably, but the reasons given for this superiority are much less satisfactory. Alford[28] says that oiliness has been defined as

> That property of an oil that influences the change in viscosity when the oil is under pressure; or, as that property that influences the intensifying of the viscosity in the portion of the oil film within the region of attraction of the surface molecules of the metals of bearing and journal.

Since it is generally recognized that animal and vegetable oils have greater oiliness than mineral oils, it would be expected from the first part of this definition that the former oils would increase in viscosity, with an increase in pressure, faster than mineral oils increase in viscosity. That this is far from being the case was found by Deeley,[29] who observed that

> Raising the pressure to 900 atmospheres increased the viscosity of vegetable and animal oils 4 times and that of mineral oils 16 times, but viscosity was clearly not the only factor to be considered.

Dunstan and Thole,[30] express a similar opinion, saying

> We feel that some other more definite criterion is needed and we propose to combine with the viscosity the determination of the surface tension, adopting for the measurement of the latter property the weight of a falling drop. . . . . A lubricating oil should contain a certain proportion of unsaturated hydrocarbons. . . . . If this view is correct, acid treatment of a lubricating oil in the course of its production should be reduced to a minimum, since it tends to remove not only the harmful resins but also the unsaturated hydrocarbons that are valuable on account of their high viscosity and body. The physical condition of a good lubricant is probably colloidal.

The idea that acid treatment is injurious and colloids beneficial has been amplified by Acheson.[31] Wells and Southcombe[32] found that surface tension, as ordinarily measured, had little significance, but that differences in oiliness, or body, were indicated by the interfacial tension between the lubricant and the adjacent metal. The theory is somewhat uncertain because it depends upon the assumption that the size of a drop formed under water is an indication of this interfacial tension. By using the drop apparatus of Donnan,[33] Wells and Southcombe found that the interfacial tension was less for vegetable and animal oils than for mineral oils, but that the addition of a relatively minute amount of fatty acid to a neutral mineral oil reduces the tension to that of a commercial animal or vegetable oil or compounded lubricating oil.

The possibility that good oiliness is due to high adhesion or adsorption is often overlooked on account of the assumption that adhesion is always adequate. Ever since Warburg[34] showed that there was no slip at the walls of a capillary tube, all equations of hydrodynamics have been simplified by making the coefficient of adhesion equal to infinity; although Warburg merely showed an absence of slip under the conditions of his tests, and did not prove that adhesion or adsorption would be sufficient to prevent slip if the shearing forces were increased greatly. In cases of high pressure and insufficient supply of lubricant, the load will be concentrated on a small area, the film will be extremely thin and, accordingly, the shearing stresses will be very high. Thus, in an article on the lubrication of gear teeth,[35] it was shown that in turbine reduction-gears the thickness of the oil film between the teeth was of the order of 0.000125 in. (0.00032 cm.).

A committee of the American Society of Mechanical Engineers[36] attempted to cause slip at the boundaries, by the use of even thinner films with a tapered plug rotating in a ring. They were unsuccessful, however, and concluded that

> With films as thin as 0.000025 in. (0.000064 cm.) and rates of shear up to 261,000 radians per sec., at atmospheric pressure and temperature, there was no indication of slip and no deviation from the ordinary law of viscosity that could not be attributed to inaccuracy of the fitted surfaces.

Thus, while there is no definite proof in regard to the cause of variations in oiliness, the most promising theory appears to be that good oiliness is due to low interfacial tension between the lubricant and the adjacent metallic surfaces, aided perhaps by selective adsorption of unsaturated hydrocarbons, colloids or fatty acids.

Service Tests

In spite of the large amount of work that has been done with oil-friction testing-machines in the attempt to test the quality or oiliness of lubricants, there are

[27] See *Engineering*, vol. 108, p. 755.
[28] See Bearings and Their Lubrication, by L. P. Alford, p. 112.
[29] See *Engineering*, vol. 108, p. 758.
[30] See *Journal of the Institution of Petroleum Technologists*, vol. 4, pp. 200 and 206.
[31] See *The Forum*, May, September, October and December, 1919.
[32] See *Journal of the Society of Chemical Industry* (London), vol. 39, p. 51T.
[33] See *Zeitschrift für Physikalische Chemie*, vol. 31, p. 42; and Circular No. 124 of the Paint Manufacturers' Association of the United States.
[34] See *Annalen der Physik und Chemie*, vol. 140, p. 367.
[35] See *Engineering*, vol. 102, p. 119; and *Proceedings of the Physical Society of London*, vol. 32, part 2, p. 148.
[36] See *Journal of the American Society of Mechanical Engineers*, vol. 41, p. 537.

many experimenters who agree with Jacobus[37] that experience in making friction tests has led to the conviction that results obtained in a laboratory give no indication of the value of an oil as a lubricant in practical use. It is believed that this conclusion is too sweeping, although considerable caution must be used in interpreting the results of laboratory as well as of service tests. On account of dissatisfaction with the former, there is a strong tendency to discard them altogether and to rely on service tests. It is believed, however, that these may lead to as many erroneous conclusions as tests made with the worst friction-machines. In making a service test, a run is made on the oil previously used and then this oil is replaced by a new brand, recommended by the engineer conducting the tests. The new brand of oil often shows say 20 per cent lower friction. As a saving of 20 per cent is a considerable item when measured at the coal pile, the manufacturer readily agrees to buy the new brand of oil. Yet the apparent superiority of the new brand may be due merely to its lower viscosity, or to the higher temperature of a warmer day at the time of the second run.

Let it be assumed that there are ring-oilers, forced feed or other means of insuring complete film lubrication, so that the friction is proportional to the viscosity. Then, if the average bearing temperature is 100 deg. fahr. (37.8 deg. cent.) and the oil has a Saybolt universal viscosity of 300 sec. at this temperature, the change of viscosity and hence the change of friction will be at least 2.0 per cent per deg. fahr. (3.6 per cent per deg. cent.). A change of temperature of only 10.0 deg. fahr. (5.6 deg. cent.) is therefore all that would be necessary to produce what would appear to be the remarkable increased "lubricating efficiency" of the new oil. Even if care is taken that the two runs are made at the same temperature, the new oil selected may be of lower viscosity and hence show a lower friction. However, this is not the only point to be considered, since freedom from breakdowns and delays is of more vital importance to manufacturers than the minimum friction. The ratio of the viscosity of the oil under service conditions to the viscosity of minimum friction can be regarded as a measure of the factor of safety against seizure, and it is not always an advantage to reduce the friction at the cost of a decrease in the factor of safety. If the viscosity of minimum friction could be decreased, it would be possible to decrease the viscosity, and hence to decrease the friction, without any decrease in the factor of safety; but it seems improbable that means will be discovered for accomplishing this, since the viscosity of minimum friction has been shown to be a definite function of pressure, speed and clearance in the bearing. It would, however, be safe to employ a lower factor of safety if the danger of seizure could be reduced when the oil film is incomplete, and this is the purpose of adding solid lubricants in suspension.

The value of graphite in cases of incomplete film lubrication is pointed out in a Memorandum on Solid Lubricants,[38] in which it is stated

> Opinions appear to be unanimous that, when using graphite, motorcycle, automobile and stationary gas engines start more easily and with greater freedom. Speaking generally, half the friction in an internal-combustion engine is piston friction; the lubricating oil film is probably never complete and a certain amount of metallic contact, or dry friction, takes place. In the United States, colloidal graphite appears to be extensively used for the initial "running-in" of automobile engines; it is said to save considerable time in producing a good surface and gives the engine a good internal "skin" before leaving the builders' works.

A committee report of the Automobile Club of America[39] is of interest in this connection, but it should be realized that an automobile engine is a complicated machine, and that the interpretation of results is an even more difficult problem than with friction machines. Very high pressures have been carried by the Kingsbury and the Michell thrust-bearings[40] without excessive friction; but this is due to the peculiar construction of the bearings, which utilize the wedging action of the oil film, and is not an indication of the superiority of any lubricant.

Desirable Features of Oil-Friction Testing-Machines

It is safe to say that no one testing machine can solve all the problems of lubrication. Such questions as the effect of centrifugal force in causing deposits of sediment, the effect of reciprocating motion or the quantity of oil actually reaching a given rubbing surface, must be solved by service tests or by special machines that are simplified commercial machines; for example, the cylinder friction and lubrication testing apparatus of A. E. Flowers,[41] the Sternol machine[42] for engine cylinder oils and greases, and the Golden machine[43] for greases. Many problems in regard to deterioration in use can be solved best in the chemical laboratory. A friction machine especially suited to test oiliness is of greatest interest, therefore, to the lubricating engineer, leaving it to the machine designer to experiment with the laws of lubrication or to make special tests on special machines. No machine on the market comprises all of the following desirable features:

(1) Means for attaining as high a pressure as possible without danger of an inconveniently rapid change in area of rubbing surface due to wear. In the Lumet[44] machine, the load is concentrated on a small area by using four friction blocks forced by oil pressure against the inside of a hollow cylinder. In the Deprez and Napoli[45] machine, there are three blocks pressed against a disc. In Deeley's hand-driven machine, there are three pegs as previously described. It is important that the whole machine should be kept small and light so that the load can be applied or the machine calibrated without the use of excessively heavy weights, although this is not so essential if the load is hydraulically applied. Kingsbury[46] had means for releasing the pressure on the bearing without changing the pressure adjustment

(2) The drive should be so arranged that a sufficiently low speed can be reached; this is 9 in. per min. (0.0038 meters per sec.) according to Archbutt and Deeley.[47] A variable speed is obtained by a friction drive in the Schmitz[48] machine, which

[37] See *Journal of the American Society of Mechanical Engineers*, vol. 32, p. 825.

[38] See Bulletin No. 4 of the Department of Scientific and Industrial Research, London, p. 25; and *Aeronautics*, vol. 18, p. 195.

[39] See *Journal of the Automobile Club of America*, vol. 1, p. 208.

[40] See *Engineering*, vol. 107, pp. 502 and 765; *Motorship*, vol. 4, p. 28; and *Journal of the American Society of Mechanical Engineers*, vol. 41, p. 915.

[41] See *Proceedings of the American Society for Testing Materials*, vol. 15, part 2, p. 399.

[42] See *Engineering*, vol. 93, p. 871.

[43] See *Journal of the American Society of Mechanical Engineers*, vol. 35, p. 1143.

[44] See *Comptes Rendus*, vol. 158, p. 172.

[45] See *Dingler's Polytechnisches Journal*, vol. 226, p. 30; and *Revue Industrielle*, vol. 8, p. 53.

[46] See *Transactions of the American Society of Mechanical Engineers*, vol. 24, p. 147.

[47] See Lubrication and Lubricants, by L. Archbutt and R. M. Deeley, p. 384.

[48] See *Zeitschrift für Angewandte Chemie*, vol. 27, p. 468.

appears to be an innovation. It is desirable that the direction of rotation be reversible for facilitating the running-in of bearings. A revolution-counter is satisfactory for measuring the speed, although it would be convenient to use a tachometer also

(3) A sensitive and easily calibrated method of measuring friction. This probably would exclude the possibility of measuring dry and fluid friction on the same machine

(4) Means for supplying the lubricant in unlimited or in definitely measured quantities, together with a device for spreading it uniformly over the rubbing surfaces. A machine with forced-feed lubrication is in use at the engineering experiment station, at Annapolis,[49] and Alexander's[50] machine has both forced feed and other means for applying the lubricant

(5) Means for measuring the pressure in the oil film. This is of importance because it determines the proper point for the admission of the lubricant

(6) Means for measuring the temperature of the oil film. This could be accomplished by the insertion of a thermocouple in the bearing, in a pocket connected with the clearance space, but with a completely encased bearing, as in the machines of Kingsbury and of Meyers, this probably would not be necessary

(7) Means for controlling the temperature of the bearing, for both accuracy and to save time in testing. Goodman says that "it is hopeless to get reliable and consistent results in any bearing-testing machine unless the temperature is very carefully controlled"

(8) Means for observing the point of seizure accurately, and to prevent roughening of bearing and journal when seizure occurs. In the Hopps[51] machine, an automatic belt-shifting device operates on approaching seizure and stops the machine

(9) Means for measuring and adjusting the clearance or film thickness. This might be accomplished by a conical journal, as in the machine of Moore and Richter,[52] but the difficulties of obtaining a perfect fit in the bearing would be increased

(10) Means for changing the rubbing surfaces readily to permit the study of wear, bearing metals and efficiency of oil-grooves; and, more especially, for maintaining the rubbing surfaces at a constant smoothness when testing lubricants

Nine of the above stated requirements could be met with a journal-friction machine, but the attainment of the tenth requirement seems well-nigh impossible. Yet this last requirement is the most important of all, because it was evident from the Bureau of Standards tests that it is futile, or at least very wasteful of time and effort, to use a machine in which means are not provided to maintain rubbing surfaces of uniform smoothness. At first sight it might be considered possible to supply a journal with an interchangeable sleeve; then, the sleeve could be removed as often as desired and subjected to a standardized polishing process that would restore it to its original smoothness. The objection to this scheme is that any such polishing would change the radius of curvature and hence change the fit or the film thickness.

The best method of overcoming the difficulty appears to be by abandoning the journal type of machine entirely and adopting a lower disc with the friction applied by an upper disc, annulus or one or more blocks, the rubbing surfaces being on interchangeable veneers that can be removed for polishing. While disc machines have not been used as often as journal machines, those of Woodbury,[53] Kapff[54] and Hislop[55] are mentioned, the last being a composite machine to test journal, disc or cylinder friction. Archbutt and Deeley[56] discuss the suitability of disc and collar friction machines for oil testing, as follows:

> The wedging action of the lubricant, resulting from the different radii of the surfaces of cylindrical journals and the brasses that rest upon them, does not affect the lubrication of collar or disc-shaped surfaces to any very great extent. On this account, the loads that such flat bearings will carry are about one-eighth part of those that may be put upon journals. Collar and disc lubrication depends mainly for its efficiency upon the oiliness or greasiness of the lubricant used. Such bearings would, therefore, seem to be well calculated to give good results in oil-testing machines. Of course, they will always give comparatively high friction resistances and therefore they must not be regarded as suitable for comparison with those obtained with the cylindrical bearings of actual working machines, or machine tools. However, as the conditions that obtain in lubricated bearings become better understood, it seems likely that disc or collar machines, highly loaded and running at moderate speeds, will be more and more extensively used for oil testing purposes.

The possibility of maintaining a constant smoothness of rubbing surfaces adds one more reason for the use of disc oil-friction testing-machines to those enumerated in the above quotation.

Conclusions

(1) In comparing viscosity and friction it is necessary to use a unit of absolute viscosity, preferably the poise or centimeter-gram-second unit

(2) The viscosity in poises can be calculated from times of flow in seconds by suitable equations that are given for the viscosimeters most frequently used

(3) In estimating the change of viscosity with the temperature, it is convenient to make use of the observed fact that, with certain restrictions, the logarithmic viscosity-temperature graphs are straight lines which meet at a point

(4) Friction tests with complete film lubrication can give no information in regard to the quality of a lubricant, and viscosity is measured more readily with a viscosimeter

(5) The only use of a friction-testing machine for determining quality of a lubricant is in measuring oiliness, and this must be done at high pressures, low speeds or other conditions which cause incomplete film lubrication. It can be assumed that the pressure must be over 800 lb. per sq. in. (56.2 kg. per sq. cm.) or the speed less than 40 ft. per min. (0.20 meters per sec.)

(6) Bearing metals also should be tested with incomplete film lubrication

(7) It is impracticable to keep a constant smoothness of rubbing surfaces with a journal bearing, so that changes in friction, commonly supposed to be due to changes in quality of lubricant, are generally due to changes in smoothness

[49] See *Journal of the American Society of Naval Engineers*, vol. 26, p. 554.

[50] See *The Engineer* (London), vol. 108, p. 291.

[51] See *Engineering*, vol. 82, p. 594.

[52] See *Journal of the American Society of Mechanical Engineers*, vol. 39, p. 734.

[53] See *Transactions of the American Society of Mechanical Engineers*, vol. 1, p. 74; also, vol. 6, p. 136.

[54] See *Zeitschrift des Vereines Deutscher Ingenieure*, vol. 42, p. 553.

[55] See *Engineering*, vol. 96, p. 254.

[56] See Lubrication and Lubricants, by L. Archbutt and R. M. Deeley, p. 408.

(8) Service tests are even more untrustworthy than friction tests, because there are a multitude of bearings whose temperature cannot be controlled or estimated readily

(9) The best solution of the difficulty appears to be the use of a disc machine. The disc could be kept of constant smoothness by removing an interchangeable veneer and subjecting it to a standardized polishing process after the test of each oil, if necessary. A journal could not be kept polished in this way because the radius of curvature, and consequently the film thickness, would be changed

MARKETING GRAIN

THE commercial life of America is more closely interwoven with the grain trade than many people suppose. Out through the Middle West wheat has always been a frontier crop; every section started as a one-crop-wheat region. Money came in only once a year, directly after harvest. Even after the coming of diversification the fall of the year is the time when farmers cash in on their season's work. This being true, it is only natural that all notes and bills due from farmers should be made payable in the fall. Likewise it is natural that jobbers, wholesalers and manufacturers should expect the heaviest payments after the annual harvest.

The entire commercial system of the country has been built around the harvest season. The railroads prepare for a heavy movement of freight, the banks prepare for a flow of currency and credits into the agricultural districts to finance crop movement, manufacturers in the East bear in mind that crop-moving time is not a good time for them to borrow money, country bankers and merchants look sharply after collections, and the Western banks expect payments on the negotiable paper they have been carrying. There is a flow of money from the East to the South and West every fall; then a counterflow in the winter. In the spring, when planting-time comes, there is another but smaller westward flow of money and credits.

Since the country is all tied together commercially and industrially and the well-being of any class depends upon the welfare of every other class, it seems clear that what the farmers should strive for, in addition to equal opportunity between buyer and seller, is equal justice between buyer, seller and ultimate consumer.

Some leaders think that the farmers should control the terminal elevators and establish a big central cash-market where they can sell from samples. They point out that the terminal elevators not only receive storage charges but are able to clean and mix and regrade and thus make another profit. With a system of bonded warehouses and some means of using warehouse receipts for securing loans, together with terminal warehouses and a cash market, some of the farm leaders think it will not be necessary nor perhaps wise to recommend anything more comprehensive in the way of control. They realize that the proposal of a very radical change would mean a complete realignment of the methods of doing all business, probably causing no end of opposition and loss of good will.

When it comes to control of production the present leaders believe that this can be best left to individual judgment, provided the individuals are given unquestioned world-crop facts upon which to base their judgment. A world-wide Governmental crop-reporting service, with daily reports sent out to all parts of the country, would be of inestimable value to the farmers at planting time and curb the effect of market rumors that so frequently affect prices on the exchanges.

The farmers already own and control nearly 5000 country elevators, and these doubtless will and should be increased. They may find it advisable to take a hand in terminal marketing both as members of the exchanges and through the creation of a big cash market. The whole country is looking forward hopefully to a sane, constructive program of marketing that all interests can indorse.—P. S. Rose in *Country Gentleman.*

ENGINEERING EDUCATION

IN previous years the first consideration of those contemplating studying engineering has been how quickly they can finish the course and get out and earn money. The purely commercial point of view has been too much evident for the good of any profession, and especially so far as the impression of the public and its attitude toward the engineer are concerned. A better professional spirit no doubt is inculcated through a greater familiarity with those subjects dealing with the political, social and economic progress of humanity. It would bring the engineer closer to the public.

To my mind the physician, lawyer and minister come more closely into contact with the great majority of the people than does the engineer, and furthermore devote more time to matters that are given daily publicity in the newspapers and other publications. It is therefore to be expected that they are given greater recognition by society. This may be due not so much to their having been trained in the "higher education" any more than engineers, for sometimes the contrary appears to be evident, judging from the position taken by some of them on important questions concerning the best interests of the public.

The aloofness of engineers in general from association with the lay public in helping to determine public policy and assisting in clarifying the minds of non-technical men in matters that may need at times the benefit of the judgment and imagination of the scientifically trained person, and even in cases where scientific or technical questions are not involved, would continue to keep the engineer in the background so long as that attitude is maintained. Commercial, governmental and public as well as semi-public officials and committees would welcome the service that engineers could bring into their various deliberations on moot questions and discussions.

The higher cultural training for the engineer would be more apt to create in him a greater interest and understanding of public affairs and greater realization that the interest of the engineer is bound up with that of the public. He will then more frequently find his place willingly and naturally alongside of men of other professions on directorates of large and small corporations, as heads of large industries and commercial or public organizations and on their committees. The public in its press would soon recognize the contribution of the engineer to the general public welfare and his lack of recognition by society would no longer be a subject calling for serious consideration by all branches of the profession.

The lack of a definite constructive policy toward developing an apprenticeship for engineers and skilled labor, is a condition that today underlies a great many of our economic troubles.

In Europe it would be evident to any American engineer visiting there, how different the attitude of the public is toward the technical professions, how much more the engineer and engineering associations are devoted to an interest in public affairs, and how much they assist in formulating policies and activities. The higher cultural education generally of European engineers is perhaps accountable for this. —Maurice Deutsch in *Engineering News-Record.*

RAILROAD ELECTRIFICATION

RAILROAD electrification, perhaps, appeals to a larger part of the public than power for industrial use. For 20 years or more the electrification of railroads has been a subject of general interest. From time to time, as certain railroads have changed from steam to electrical operation for portions of their lines, the passing of the steam locomotive has been confidently predicted by experts who have been impressed with the superiority of electric traction, but the steam locomotive not only appears to be holding its own, but by notable improvements in design and appurtenances seems recently to have taken a new lease of life. Outside of the work on the Chicago, Milwaukee & St. Paul Railway there have been very few electrical installations in trunk lines in the past 4 or 5 years.

Advantages of Electrification

The major advantages of electrification are well known. In general they include increased line capacity, because of increased train speed and heavier train loading; fuel economy, because of the more efficient conversion of heat units into power; lower maintenance costs, because electric locomotives require less repairs than steam locomotives of equal capacity; and increased serviceable locomotive hours, because the electric locomotives can be used more continuously and require less terminal attention between trips.

Besides these strictly operating features there are important social advantages. These appeal particularly to the general public. The elimination of smoke makes traveling more comfortable and adds to the value of nearby property. Electric traction has made possible the remarkable development of the property surrounding and the track approaches to the Grand Central Terminal. Electrification of the lines radiating from Boston, as a single example, would be of immense value to the community by abating the smoke nuisance, reducing noise, adding to terminal capacity, and increasing property values. Without electricity as motive power it would be impracticable to operate trains through tunnels such as those in New York City, Baltimore and Detroit, the Hoosac Tunnel of the Boston & Maine, the Cascade Tunnel of the Great Northern and others that might be named. The electrification of the mountain grades of the St. Paul and Norfolk & Western roads has made heavier trains possible, has, by regenerative braking, reduced the risk of handling heavy trains on descending grades and has increased road capacity.

Problem One of Finance

Practically all of the electrical installations on trunk lines have been designed to meet special operating conditions, such as tunnels or city terminals. No large railroad has been completely electrified. There is an absence of data that can be used in studies of complete electrification. Railroad executives therefore will be much interested in the Superpower Survey, hoping that it may contain information that can be applied to their local conditions. The typical railroad executive recognizes the advantages of electrical operation. He knows that it will eventually displace steam, at least on lines of heavy traffic and in congested terminals. For his own line under these conditions he would welcome the advent of electricity if a fairy godmother would provide the capital funds and make it possible to earn the additional carrying charges. The problem is not one of engineering. It is essentially one of finance.

If the estimates of the Superpower Survey engineers as to savings in expenses and return on capital investment could be accepted without reservation the financial problem would be easier of solution. Unfortunately, however, this is not the case. The figures are subject to material qualification. There is evidence of an inclination to go out of bounds in making a case in favor of electricity and against steam. The zeal of the electrical engineer, who is firmly convinced as to the general soundness of his conclusions, is only natural but the report would carry much greater weight if it were less biased.

For example, in the item of fuel the electrical engineers have assumed that a steam locomotive requires 7½ lb. of fuel for each kilowatt-hour of work at the rim of the drivers. Against this they set an estimate of 2 lb. under electrical operation. From these data it is assumed that electrification will save two-thirds of the fuel bill.

It should be noted, however, that the estimate for the steam locomotive is based on experiments made 11 years ago on the St. Paul, with a type of locomotive now considered as practically obsolete. It was not as powerful as the typical locomotive of today, nor was it equipped with other devices now common on modern locomotives. A comparative test with the heavier locomotive of today, equipped with modern appliances for economizing in fuel, would give far different results. The estimate for fuel consumption under electrical operation was based on the performance of a powerplant of modern design.

Fuel Saving About One-Third

It is interesting to compare this theoretical saving of two-thirds of the fuel with the actual figures for the Norfolk & Western. In discussing the subject before a joint meeting of the societies of Electrical and Mechanical Engineers at New York City in October, 1920, the chief electrical engineer of that road stated that a comparison of fuel consumption on the electrified divisions with tests made with modernized Mallet type locomotives under similar conditions indicated that the saving in fuel by electrical operation was 29.3 per cent. This is less than one-third. If the Superpower Survey engineers had assumed a saving of one-third instead of two-thirds, the former is closer to the facts, the estimated fuel savings would be cut in two. A tendency to favor electrification is shown also in other items, such as in the allowance for steam locomotives released.

As has already been stated, the problem is essentially one of finance. In the case of a railroad that has an investment in road and equipment of, say, $100,000 per mile, something more than a questionable return of 14 per cent is needed to induce recommendations for an investment, of, say, $40,000 more per mile for electrification. On every hand there are needs for additional investments of other kinds that without question will yield more than 14 per cent.

Change Will Come Piecemeal

The Superpower Survey will probably stimulate further discussion of railroad electrification. Notwithstanding the defect that has been mentioned, the report is constructive and should be regarded as a valuable contribution to engineering and economic literature. When the railroads are again on their feet there will probably be further extensions of electrification where the conditions are most favorable.

It is improbable, however, that electrification on any such scale as is recommended by the report will be attempted. It will come piecemeal and gradually. The electrical engineers still have much to learn. The electric locomotive is still in the experimental stage. It is likely to undergo many changes in design and the experts have yet to agree on important fundamentals. While the electrical engineers are fighting among themselves the battle of alternating versus direct current and overhead construction versus third rail the mechanical engineers are unwilling to allow their electrical colleagues to stage the obsequies for the steam locomotive at the present time.—Prof. W. J. Cunningham in *New York Evening Post.*

DAY
SIDE GUIDE AND GRIPPER

Continuous Die Rolling

By G. R. NORTON[1]

ANNUAL MEETING PAPER *Illustrated with* PHOTOGRAPHS

THE process of continuous die rolling and the products possible with this method of manufacture are described and illustrated. The improvements that have been made were the result of efforts to produce more complicated sections by this process, with greater accuracy, and these are discussed at some length.

The physical characteristics of steel that must be considered are commented upon and forming that is effected in one pass is described, consideration being given the requirements of rolled forging blanks.

The cost of operation is treated and the equipment used is discussed, showing how this process differs from other methods of making the same things, as to both the operations necessary and the character of the product.

CONTINUOUS die rolling is the process of producing bars in which the form of cross-section is varied according to impressions sunk in the pair of rolls between which the final pass is made. At each revolution of the rolls the design cut in their surfaces is repeated on the bar passing between them, and the number of these repetitions is limited only by the length of the bar as is shown in Fig. 1.

FIG. 1—TIE RODS PRODUCED BY THE CONTINUOUS DIE ROLLING PROCESS AS THEY ARE DELIVERED FROM THE ROLLS

Wagon-box straps and axle-clip sections have been produced in this manner for years. In these bars, a round alternates with a half-oval or bevel-edged flat and the change in section is accomplished by passing a round bar between the rolls, allowing the bar to pass for a certain distance without change, after which it is flattened and spread for the desired length of this part. The number of round and flat sections produced at each revolution will, of course, depend on their lengths and the diameters of the rolls.

In rolling sections of this character it is not necessary that impressions be formed in both rolls, because the round has been produced by straight rolling and it is only necessary to change its shape; so, one roll can have a plain surface with the impression cut in its mate. This usually results in a slight flattening of the round, which would be objectionable if great accuracy of size were required. The bars become oversized as the rolls wear in service and, if dressing is done by turning off the surfaces of the rolls and recutting the impressions, a loss in circumferential length results which changes the lengths of the impressions.

IMPROVEMENTS IN THE ART

Continuous die rolling as developed by the Witherow Steel Co. has as its basis the production of more complicated sections with greater accuracy. This is accomplished by building up the active surfaces of the rolls, instead of sinking impressions in the ordinary roll casting. Cast or forged rings of material suitable to the character of the section to be rolled are cut into segments in the outer surfaces of which complete impressions or parts of impressions are sunk, and the rings are assembled on mandrels to which they are locked. This segmental construction, or building up the groove, involves but little material as compared with a solid roll, and provides for easy and inexpensive dressings, repairs or changes. Wear on these rolls can be compensated for in various ways and the length of any impression held constant.

To produce sections symmetrical about their longitudinal axes, followed by other sections that may be offset, it is necessary to provide for the exact matching of the opposing rolls. This is done by mounting pinions on the rolls opposite the driven side. As only one roll is driven from the roll train and always in the same direction, these pinions are used to match the rolls exactly and are provided with adjusting devices for this purpose. Once the rolls are properly matched, there is no variation in the alignment of the impressions. It can be seen easily that, to handle this class of work economically, considerably more equipment than one finishing stand of rolls is necessary. The leader or bar on which the forming pass is made cannot in all cases be a predetermined shape, and must be found by trial. Frequently, leaders are made that do not conform to any standard commercial shapes and would, therefore, be difficult and costly to obtain. The heating, handling and rolling of single bars would operate against good production and increase costs. It is necessary, therefore, to work from billets that are roughed-down and rolled to the desired form of leader according to usual rolling practice, and finished in the same heat. This method has a considerable advantage metallurgically, because the billets are brought slowly from atmospheric to rolling temperature in continuous furnaces and can be timed to take the last pass at the proper finishing temperatures. The metal is worked uniformly and completely in one direction and its flow, as exhibited by studies of the macrostructure, is more uniform than in forging.

It should be understood clearly that continuous die rolling bears no relation to the forming of variable-section bars on forging or eccentric rolls, where the stock is cut

[1] Steel works manager, Witherow Steel Co., Pittsburgh.

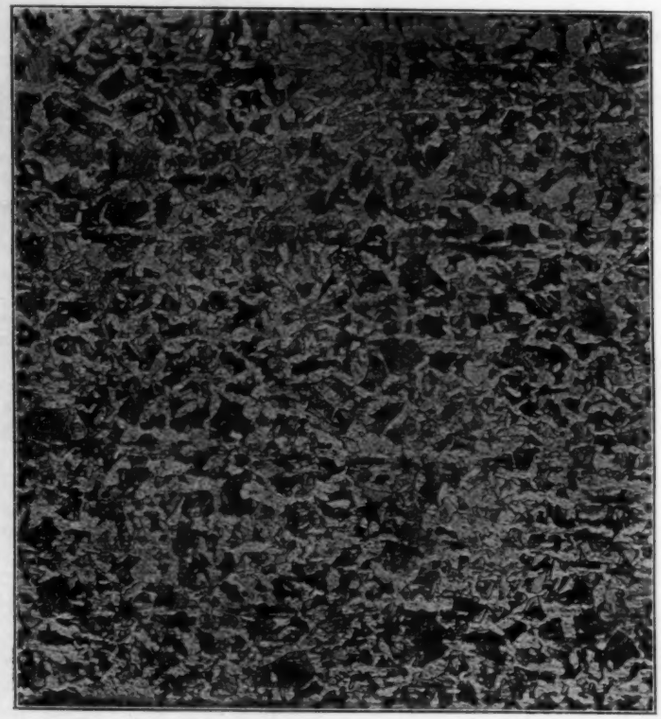


FIG. 2—PHOTOMICROGRAPH MAGNIFIED 100 DIAMETERS OF AN UNTREATED ROLLED SHAFT

to the desired weight and each piece is handled individually, a large number of passes being made and the stock rotated 90 deg. at each pass.

PHYSICAL CHARACTERISTICS

Generally, it is held that hammering has a refining effect on steel and is a much superior method to rolling. Charpy showed by experiment and tests that certain physical properties are varied according to the amount of work done, independently of the method. By the amount of work done is meant the reduction of area from the original to the finished section, and the ratio of the original area to the worked area is called the coefficient of work.

To demonstrate the relative values of different processes, the amount of work done being the same, a 2-in. round billet of 0.45 per cent carbon open-hearth steel was rolled into a rear-axle drive-shaft having maximum diameters of 1-9/16 in. at the wheel and spline ends and a minimum diameter of 1-3/16 in. at the end of the long taper next to the spline end. From the same billet, duplicates of this shaft were forged and a bar was rolled 1-3/16 in. in diameter on which upsets, 1-9/16 in. in diameter were made, the lengths of the upset being the same as those of the rolled and forged shafts. The reduction of area from the billet to the smallest diameter of the shaft was 64.75 per cent, or a coefficient of work of 2.84.

Charpy impact-tests were taken on the axes of the shafts at the point of junction between the long taper and the spline end, and an examination made of the microstructure and macrostructure. A second set of shafts duplicating the first was heated to 840 deg. cent. (1544 deg. fahr.), held 15 min., quenched in oil and the impact tests and microscopic examinations repeated. Table 1 shows the result of these tests and indicates

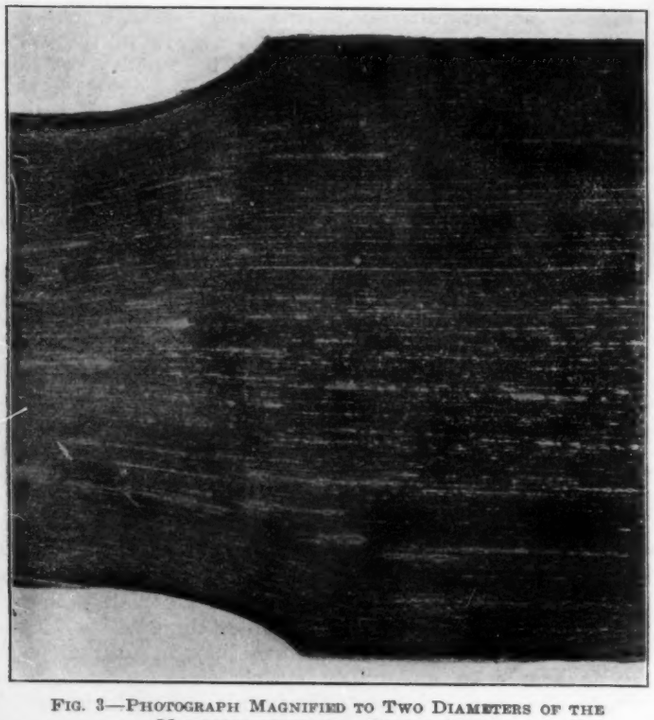


FIG. 3—PHOTOGRAPH MAGNIFIED TO TWO DIAMETERS OF THE MACROSTRUCTURE OF A ROLLED SHAFT

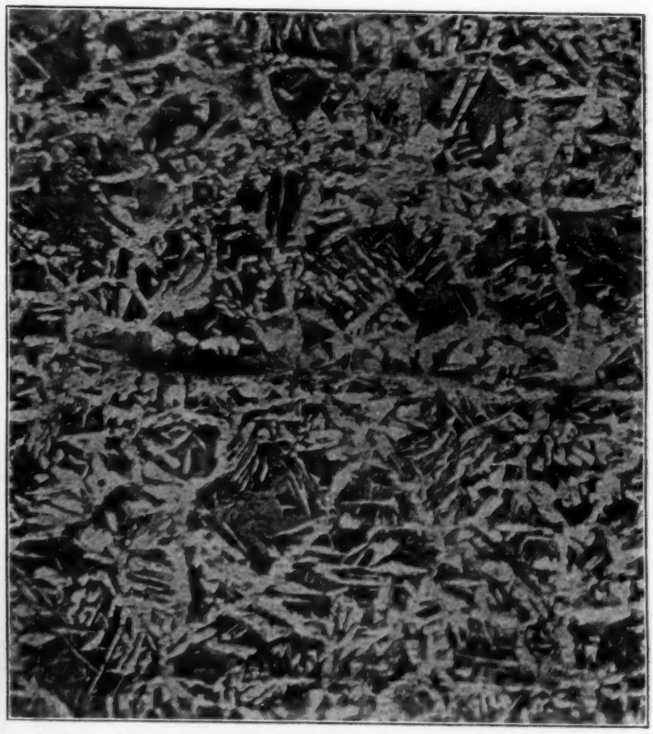


FIG. 4—MICROSTRUCTURE MAGNIFIED TO 100 DIAMETERS OF AN UNTREATED FORGED SHAFT

TABLE 1—CHARPY IMPACT-TESTS

Test Made on	Energy Absorbed, ft-lb.	Strength, per cent	Increase by Treatment, per cent
Rolled Shaft, Untreated	13.59	100.0	.....
Forged Shaft, Untreated	6.32	46.5	.....
Upset Shaft, Untreated	4.85	35.7	.....
Rolled Shaft, Treated	18.06	100.0	32.9
Forged Shaft, Treated	14.08	77.8	123.0
Upset Shaft, Treated	10.83	60.0	123.2

that the method of working is a factor to be considered seriously in connection with the physical properties of steel.

Figs. 2 to 7 show a smoother and more uniform flow of metal in the rolled specimens than the others and a better refinement of grain-size before treatment. This is due to the fact that continuous die rolling is a continuous process of working rather than discontinuous as in forging, upsetting or eccentric rolling.

Forming Effected in One Pass

In continuous die rolling, it is not possible to make successive forming passes to give a product like that illustrated in Fig. 8 because of the difficulty in entering a partially formed bar at exactly the right point in the impressions in the rolls; so, the entire forming must be accomplished in one pass. When very great reductions of area are necessary, some flash or overfill will occur

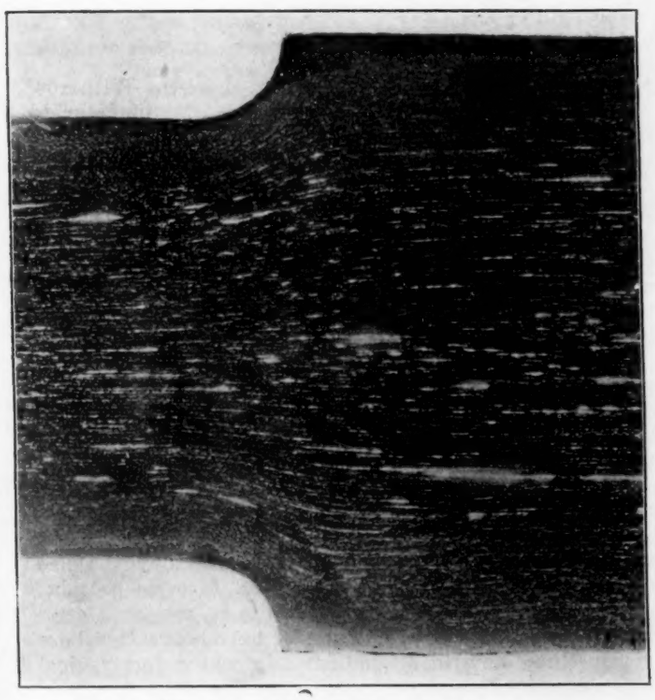


Fig. 5—Photograph Magnified to Two Diameters of the Macrostructure of a Forged Shaft

as is shown in Fig. 9. The bar will be extruded between the rolls to a considerable extent but, at some point, depending upon the character of the section, the volume displacement cannot be carried further in the impressions and the rolls spring apart, relieving the grooves and allowing a portion of the metal to spread between the faces of the rolls. This flash can be controlled to some extent and may vary in thickness from 1/32 to 1/8 in. As the bar does not rotate in the pass, any flash produced is straight and can be removed easily by trimming, giving the result illustrated in Fig. 10.

It has been found that the sectional forms into which bars are changed materially affect the amount of flash and extrusion that takes place, and no rule has been found to govern all cases. However, because the rolling is in effect reducing or drawing with but little spreading action, the flash will always be considerably less than would be produced on the same piece under a hammer and, consequently, the wastage of stock is less.

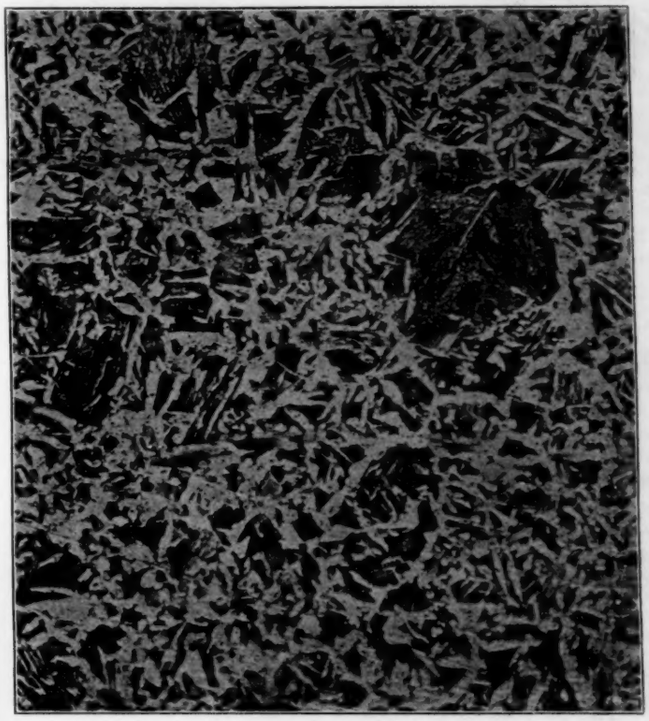


Fig. 6—Photomicrograph Magnified to 100 Diameters of an Upset Shaft

Rolled Forging Blanks

Many forgings require preliminary operations, such as upsetting or drawing, before the stock is in such form as to be struck easily in finishing impressions without excessive waste and wear on dies. Frequently, so much work of this character is involved that two tools are necessary to complete the forging and, as the prelim-

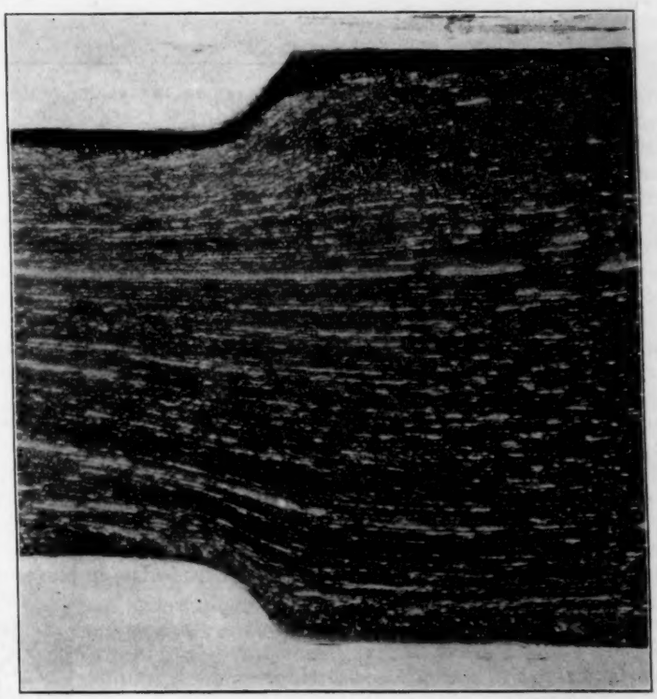


Fig. 7—Photograph Magnified to Two Diameters of the Macrostructure of an Upset Shaft

FIG. 8—A BAR WITH ROUND, SQUARE AND HEXAGONAL CROSS-SECTIONS AND BOSSES PRODUCED BY THE CONTINUOUS DIE ROLLING PROCESS

inary and finishing operations are not balanced exactly, and in many cases cannot be completed in one heat, time is lost and much expense is incurred. Continuous die rolling provides a means of supplying blanks for forging that can be struck directly in the finishing impressions in the dies, or struck after one or two edging blows if offsets or bends are required to be made. A properly designed blank can be reproduced with great accuracy, eliminating the forging scrap caused by blanks made improperly under the hammer.

Front-axle I-beam blanks, Fig. 11, that can be finished under one hammer for either the Elliott or reversed-Elliott type of axle, can be rolled. Blanks for camshafts, ready to strike for finishing, can be rolled, thus eliminating the blocking or upsetting operations and the rolling-in dies immediately preceding forging. Spring-clips can be rolled with the offsets for bending exactly as forged. A small amount of flash is produced, which requires cold-trimming before the clips are bent. Rear-axle drive-shafts can be rolled and, after trimming, are ready for hardening and machining.

The product of continuous die rolling is received from the mill in the form of long bars, in lengths that are multiples of the lengths of the individual pieces. The

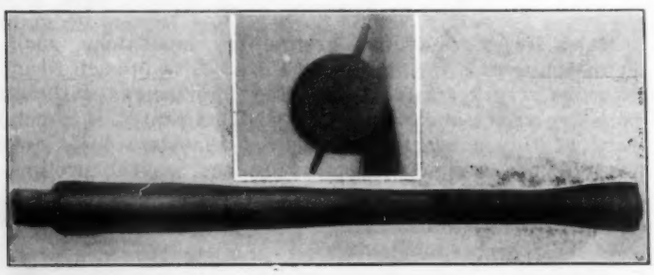


FIG. 9—PHOTOGRAPH OF A REAR-AXLE SHAFT AS ROLLED SHOWING THE FLASH PRODUCED IN THE PROCESS IN THE LOWER PORTION WHILE THE SMALL INSERT IS A CROSS-SECTION OF THE SHAFT SHOWING THE RELATIVE PROPORTIONS OF THE SHAFT AND THE FLASH

length of these bars will depend upon the weight of billet used. After cooling, they are cut into ordinary mill lengths or into single pieces. After this, trimming or any finishing operations can be performed.

COST OF OPERATION

Quantity is obviously essential to the economy of operation, because the expense of cutting rolls and setting up a mill could not well be carried by a few pieces. The cost of this type of conversion naturally must be greater than ordinary conversion from billets to bars, for this work is necessary as a preliminary to the final die forming; also, to the bar-conversion cost must be added the costs of the die rolls and their maintenance, special forms of guides for delivery and adjusting gears for matching rolls. Production is decreased also, because of the necessity for lower mill speeds than are usual in rolling practice.

In addition to working out the patented features of roll construction and mill design, a long and costly series of experiments was necessary before continuous die-rolled products could be marketed and sufficient data collected to predict with reasonable accuracy the performance of any given variable section. Conversion is made on the usual basis of 1 gross ton of billets to 1 net ton of bars, the bar weight including any flash or gates between impressions of course.

EQUIPMENT USED

The size and length of pieces produced by continuous die rolling are limited only by the capacity of the mill and the diameters of rolls that can be accommodated in

FIG. 10—THE REAR-AXLE SHAFT SHOWN IN FIG. 9 AFTER TRIMMING

the housings. The equipment operated by the Witherow Steel Co. covers sections from 5/16 in. in diameter to 3-in. squares; and the lengths of individual impressions may vary from a fraction of an inch to 17½ ft., rolls 68 in. in diameter being necessary for this length. The application of the product of this process is largely a matter of the study of local conditions in any manufacturing plant, but the automotive industry generally offers a wide field for its consumption by reason of its quantity-production requirements and the large number of forgings used.

No attempt has been made to do more than describe, without much detail, the operations and equipment used to manufacture by continuous die rolling, and to show how it differs from other methods of making the same things, as to both the operations necessary and the character of the product. From its beginning, the practice of rolling has been improved only along the lines of increasing the tonnage capacity of mills, without much effort to depart from the manufacture of standard rolled shapes and bars of constant area and form of section; so, the development of continuous die rolling on a commercial basis for the production of variable-section bars is something new in an industry in which few radical changes have taken place.

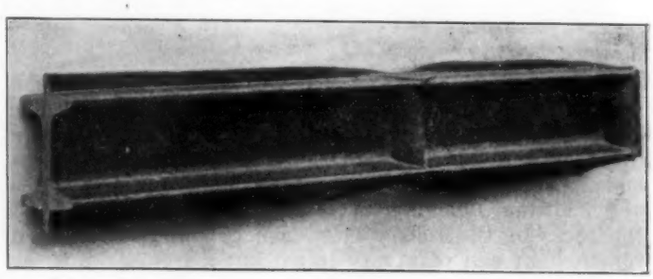


FIG. 11—A FRONT AXLE OF I-BEAM SECTION SHOWING THE BOSSES AND THE FLASH

This Was a Difficult Rolling Problem on Account of the Marked Changes in the Cross-Sectional Area

Chrome-Molybdenum-Steel Applications from the Consumer's Viewpoint

By C. N. DAWE[1]

ANNUAL MEETING PAPER *Illustrated with* CHARTS

THIS paper gives a plain statement of facts regarding the application of chrome-molybdenum steels, as noted by a large manufacturer of automobiles, more than 2000 tons of molybdenum steels of various compositions having been consumed in tests and the manufacture of all the important steel parts such as transmission and differential gears, rear-axle shafts, transmission shafts, steering-knuckles, steering-knuckle pins, and the like. The data of an extensive set of physical tests are given, comparing medium-carbon, chrome-molybdenum, chrome-vanadium, chrome-nickel and chrome steels, and the results are expressed by means of a merit index, taking into consideration yield-point, ultimate-strength, elongation and reduction of area.

The case-hardening grades of steel are discussed, difficulties that were encountered in the use of the low-carbon chrome-molybdenum steel in this connection being specified. The possibilities of nickel-molybdenum steel for case-hardening purposes are considered, the results so far indicating that it is a strong rival of low chrome-nickel steel, which is considered the best steel for commercial case-hardening at present.

IN venturing to cover this pertinent subject it should be stated that there are so many more data yet to be obtained that it is impossible, at this time, to make a definite statement that fully covers the situation with regard to the application of commercial chrome-molybdenum steels. Such propaganda has been spread with reference to these steels and so much has been written regarding the history, possibilities, sources of supply and physical properties obtained, that there are many consumers as well as manufacturers who are looking on in a doubtful yet open frame of mind, desiring to gain further information, particularly with reference to application. It is with this in mind that I present some actual data with reference to commercial molybdenum steel noted from the viewpoint of a large consumer and not that of a fabricator or salesman. I say from the viewpoint of a consumer because, at times, the fabricator or steel manufacturer seemingly has the weird knack of always obtaining the maximum physical properties from a material he wishes to promote, and the promoter often speaks in even higher terms. However, we as consumers attempt to strike rock-bottom and note what the material will actually do under production requirements.

Before proceeding too far with the presentation of the data and conclusions drawn, I wish to emphasize the fact that every manufacturer of automobiles and automobile parts has his own peculiar problems and that frequently the means to an end in one plant is not applicable in another; therefore, there undoubtedly will be some criticism and discussion of the publication of the information given herein, although it is presented from a strictly neutral attitude and with no idea of promoting or discouraging the use of molybdenum steels.

An attempt is made to give the results of the tests made and the observations noted in as practical a manner as possible, in order that they may be easily understandable and thereby prove of commercial value. A theoretical discussion of the causes of the manner in which molybdenum steels act will be avoided, since this phase already has been well covered by those whose opinions and discussions carry much more weight because of their many years of experience in the manufacture and application of molybdenum steels. For those who are sufficiently interested, it is recommended that the recent papers of Dr. John A. Mathews[2] and Dr. G. W. Sargent[3] be read.

MOLYBDENUM-STEEL USAGE

The Studebaker Corporation of America has had made and shipped to its plants over 2000 tons of molybdenum steels of various analyses. This steel has been put through production in the form of rear-axle shafts, transmission gears and shafts, steering-knuckles, steering-knuckle pins, ring gears and drive pinions; in fact, all parts for which alloy-steel is specified. Our first efforts were to determine the advisability of the adoption of that class of chrome-molybdenum steel which would be adaptable to heat-treated forgings such as steering-knuckles, steering-arms and rolled axle-shafts, water quenching of these being desired. By a process of elimination it became clear that steel containing molybdenum approximating 0.30 to 0.40 per cent, with chromium 1.00 per cent and carbon above 0.30 per cent, should be avoided when water is desired as the quenching medium and where cracker shearing is used. An analysis showing a carbon-content below 0.30 and above 0.23 per cent, with a chromium-content of 0.70 to 0.90 per cent and molybdenum 0.30 to 0.40 per cent, gives satisfactory results with water as a quenching medium, there being no cause for concern pertaining to the development of quenching cracks.

As a rule, our first interest is turned toward the physical properties of a steel as compared to those with which we already are acquainted. Having this in mind, an extensive test was run involving the pulling of approximately 400 tension-pieces turned from heat-treated stock varying in size from $\frac{7}{8}$-in. round to 2-in. square. The sizes used were $\frac{7}{8}$, 1 and $1\frac{1}{2}$-in. rounds and 2-in. squares. The three smaller sizes were obtained by forging down from the 2-in. square hot-rolled forging bars. The 2-in. square test-pieces were taken directly from the bar, no work having been put upon them. The wide heat-treating range of a given steel is a property upon which great stress always seems to be laid but, in our tests, no attempt has been made to determine this. In this present day of accurate metallurgical control we do not need a 100 to 200-deg. quenching range. What we as consumers are mostly interested in is to determine the low-

[1] Metallurgical engineer, Studebaker Corporation of America, Detroit.

[2] See *The Iron Age*, Feb. 24, 1921, p. 505.

[3] See *Transactions of the American Society for Steel Treating*, vol. 1, p. 589.

TABLE 2—RESULTS OF TESTS OF ⅞-IN. ROUNDS

Grade of Steel	Temperature, deg. fahr. Quenching	Drawing	Yield-Point as Elastic-Limit, lb. per sq. in.	Ultimate-Strength, lb. per sq. in.	Elongation in 2 In., per cent	Reduction of Area, per cent	Number of Tests Made	Merit Index
Chrome Molybdenum	1,550 to 1,650	1,000	146,850	158,530	21.2	55.6	9	72.8
Chrome Vanadium	1,550 to 1,650	1,000	148,900	157,770	19.4	54.6	9	65.5
Chrome	1,550 to 1,650	1,000	124,637	140,124	16.9	58.1	9	53.4
Chrome Nickel	1,475 to 1,575	1,000	119,861	135,164	18.5	59.5	9	58.2
Chrome Molybdenum	1,550 to 1,650	1,100	122,733	136,966	22.5	60.7	9	74.3
Chrome Vanadium	1,550 to 1,650	1,100	127,570	140,030	22.7	57.5	9	71.5
Chrome	1,550 to 1,650	1,100	104,911	121,108	20.5	64.0	9	64.3
Chrome Nickel	1,475 to 1,575	1,100	107,266	122,888	20.5	62.8	9	63.4
Chrome Molybdenum	1,550 to 1,650	1,200	100,980	118,900	26.5	68.4	9	92.2
Chrome Vanadium	1,550 to 1,650	1,200	119,000	131,983	23.6	60.6	9	75.2
Chrome	1,550 to 1,650	1,200	97,111	113,699	21.7	64.8	9	65.0
Chrome Nickel	1,475 to 1,575	1,200	94,804	111,800	21.7	65.0	9	64.0

est quenching-temperature that can be used commercially and still obtain the maximum physical-properties. With this in mind, quenching temperatures ranging from 1550 to 1650 deg. fahr. were used in the case of the chrome-molybdenum, chrome-vanadium and chrome steels, while 1475 to 1575 deg. fahr. were used with the chrome-nickel steel.

Methods of Testing

To obtain results as nearly accurate commercially as possible, each group of test-pieces was quenched from a production furnace in the same manner as small forgings would be handled in receiving similar treatment. The drawing operations were carried on in a laboratory electric furnace so that the effect of the drawing temperature would be defined sharply. The physical properties we obtained, true to our expectations, showed occasional variations which were to our dislike, but were fairly evenly distributed over the four types of steel. In this connection, in nearly all cases, in publishing the physical properties of a given steel there is such an exact uniformity of the superiority of one steel over another, or such an exact uniformity in the variations of the elastic-limit and ultimate-strength with respect to the elongation and reduction of area under different treatments, that it is apt to throw an element of doubt into the mind of one who can appreciate the very peculiar and pronounced variations that do exist under the most accurate handling of test-pieces. The ultimate findings of the tests given herewith, however, were derived from a very broad average of results, including good and bad which we must admit is the proper way to form conclusions on a problem of this kind. The chemical analyses of the various types of steel tested are shown in Table 1.

TABLE 1—CHEMICAL ANALYSIS OF VARIOUS TYPES OF STEELS TESTED

	Chrome Molybdenum	Chrome Vanadium	Chromium	Chrome Nickel
Carbon	0.260	0.320	0.310	0.280
Manganese	0.570	0.750	0.850	0.720
Sulphur	0.020	0.033	0.012	0.012
Phosphorus	0.025	0.025	0.020	0.020
Chromium	0.800	1.030	0.910	0.580
Molybdenum	0.360	....	....	....
Vanadium	....	0.160	....	....
Nickel	....	....	....	1.270

Quenching and Drawing Temperatures

As has been stated, three quenching temperatures were used for each type of steel for each size, except for the 2-in. square as noted. Also, three drawing temperatures were used for each quench for each size, 1000, 1100 and 1200 deg. fahr.; that is, nine pieces of ⅞-in. round stock were quenched from a given quenching temperature and three were drawn at 1000 deg., three at 1100 deg., three at 1200 deg. fahr., and so on through the series. The results obtained, as shown by averages, are given in Tables 2, 3, 4 and 5.

Generally speaking, in performing tests of the above nature where we desire to note a comparison of the physical properties of certain steels in terms of the elastic-limit, ultimate-strength, reduction of area and percentage of elongation, sometimes we are confused because of the variations we obtain, and because it is practically impossible, over a large number of test-pieces, to hold any one or two factors constant so as to note the variation in the remaining factors. If we could heat-treat the test-pieces so that the elastic-limit would be the same in all, the variation in the other three remaining factors would tell the story. After having made hundreds of tests, the question then presents itself as to how best to interpret the results obtained. Without entering into any discussion on this point, I take the liberty of using the merit index suggested by H. T. Chandler, and

TABLE 3—RESULTS OF TESTS OF 1-IN. ROUNDS

Grade of Steel	Temperature, deg. fahr. Quenching	Drawing	Yield-Point as Elastic-Limit, lb. per sq. in.	Ultimate-Strength, lb. per sq. in.	Elongation in 2 In., per cent	Reduction of Area, per cent	Number of Tests Made	Merit Index
Chrome Molybdenum	1,550 to 1,650	1,000	153,880	162,200	19.4	55.9	9	69.7
Chrome Vanadium	1,550 to 1,650	1,000	147,750	158,770	19.8	54.8	9	67.2
Chrome	1,550 to 1,650	1,000	124,872	138,066	17.0	57.9	9	53.1
Chrome Nickel	1,475 to 1,575	1,000	120,860	136,086	18.1	59.9	9	58.0
Chrome Molybdenum	1.550 to 1,650	1,100	112,400	129,000	24.7	64.7	9	84.6
Chrome Vanadium	1,550 to 1,650	1,100	127,100	139,300	23.4	58.3	9	74.8
Chrome	1,550 to 1,650	1,100	99,706	116,526	20.6	63.8	9	61.5
Chrome Nickel	1,475 to 1,575	1,100	103,740	121,330	21.1	63.6	9	65.2
Chrome Molybdenum	1,550 to 1,650	1,200	99,330	117,400	27.1	66.7	9	88.3
Chrome Vanadium	1,550 to 1,650	1,200	101,950	116,500	26.9	64.8	9	83.4
Chrome	1,550 to 1,650	1,200	96,390	112,766	21.9	66.2	9	67.7
Chrome Nickel	1,475 to 1,575	1,200	92,590	111,013	22.1	65.5	9	65.2

TABLE 4—RESULTS OF TESTS OF 1½-IN. ROUNDS

Grade of Steel	Temperature, deg. fahr. Quenching	Drawing	Yield-Point as Elastic-Limit, lb. per sq. in.	Ultimate-Strength, lb. per sq. in.	Elongation in 2 In., per cent	Reduction of Area, per cent	Number of Tests Made	Merit Index
Chrome Molybdenum	1,550 to 1,650	1,000	147,900	157,600	20.3	57.0	9	72.2
Chrome Vanadium	1,550 to 1,650	1,000	129,800	140,200	20.9	57.6	9	66.6
Chrome	1,550 to 1,650	1,000	101,370	122,178	18.1	60.8	9	51.6
Chrome Nickel	1,475 to 1,575	1,000	103,360	123,036	18.7	61.1	9	54.1
Chrome Molybdenum	1,550 to 1,650	1,100	118,500	131,900	24.0	64.4	9	84.3
Chrome Vanadium	1,550 to 1,650	1,100	117,800	134,900	23.5	61.0	9	76.1
Chrome	1,550 to 1,650	1,100	86,770	109,710	21.9	65.0	9	61.4
Chrome Nickel	1,475 to 1,575	1,100	87,720	110,492	22.3	65.5	9	64.0
Chrome Molybdenum	1,550 to 1,650	1,200	92,900	112,400	26.9	68.8	9	88.7
Chrome Vanadium	1,550 to 1,650	1,200	102,400	118,500	26.5	67.0	9	88.8
Chrome	1,550 to 1,650	1,200	78,250	103,453	23.7	67.2	9	65.6
Chrome Nickel	1,475 to 1,575	1,200	80,417	103,577	24.6	67.8	9	70.3

presented in a paper by John D. Cutter,[4] and of expressing the results obtained above in terms of the equation

$$I = [\tfrac{1}{2}\, e(E + S) \div (100 - R)$$

where

I = the merit index
e = the percentage of elongation in 2 in.
E = the elastic-limit in terms of 1000 lb. per sq. in.; in the tests it is taken as the yield-point
R = the percentage of reduction in area
S = the ultimate-strength in terms of 1000 lb. per sq. in.

[4] See *Transactions of the American Society for Steel Treating*, vol. 1, p. 188.

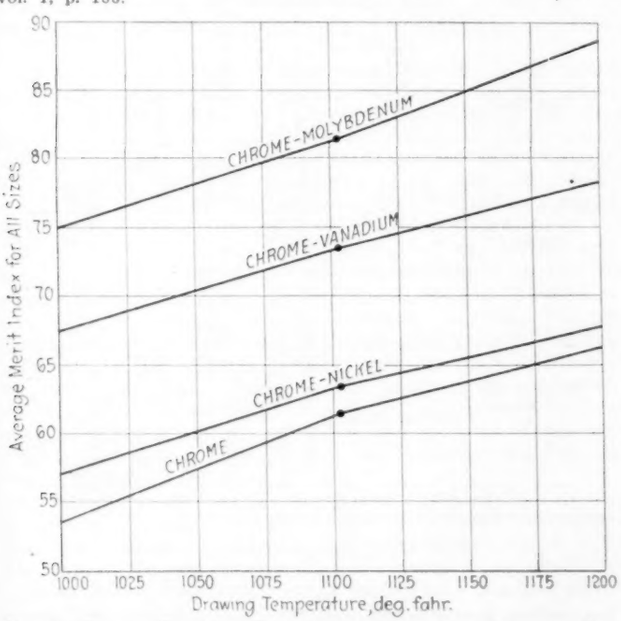


FIG. 1—CURVES SHOWING RELATION BETWEEN THE DRAWING TEMPERATURE AND THE AVERAGE MERIT INDEX FOR VARIOUS ALLOY-STEELS

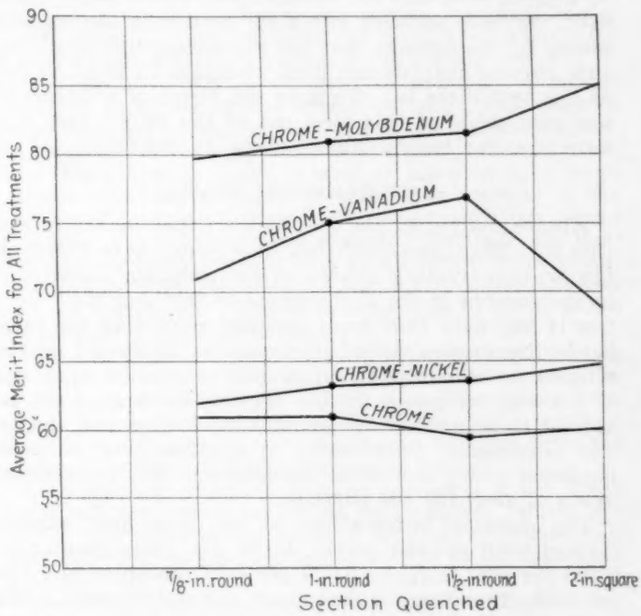


FIG. 2—CURVES SHOWING THE RELATION BETWEEN THE AVERAGE MERIT INDEX AND THE SIZE OF SECTION QUENCHED

The results are noted in Tables 2, 3, 4 and 5, while a general average is shown by the curves in Figs. 1 and 2. The above data or tests have indicated to us that chrome-molybdenum steel for heat-treated automobile parts has considerable merit. In view of the fact that this steel apparently can be produced in unlimited quantities with no danger of shortage of molybdenum, and because it has been produced and sold at a lower price than its closest competitor, chrome-vanadium steel, its adoption has been sanctioned.

With reference to its action through various stages of

TABLE 5—RESULTS OF TESTS OF 2-IN. SQUARES

Grade of Steel	Temperature, deg. fahr. Quenching	Drawing	Yield-Point as Elastic-Limit, lb. per sq. in.	Ultimate-Strength, lb. per sq. in.	Elongation in 2 In., per cent	Reduction of Area, per cent	Number of Tests Made	Merit Index
Chrome Molybdenum	1,550 to 1,600	1,000	108,500	125,400	27.6	62.0	2	85.0
Chrome Vanadium	1,550 to 1,600	1,000	104,400	119,500	24.2	61.5	2	70.3
Chrome	1,550 to 1,600	1,000	94,375	113,050	20.7	61.3	2	55.4
Chrome Nickel	1,475 to 1,575	1,000	96,250	119,690	19.9	62.5	2	57.9
Chrome Molybdenum	1,550 to 1,600	1,100	100,500	117,200	25.4	66.5	2	82.6
Chrome Vanadium	1,550 to 1,600	1,100	112,800	127,800	24.3	59.0	2	71.3
Chrome	1,550 to 1,600	1,100	83,750	105,700	21.8	65.0	2	59.0
Chrome Nickel	1,475 to 1,575	1,100	89,375	111,350	21.8	65.0	2	62.5
Chrome Molybdenum	1,550 to 1,600	1,200	78,800	100,600	29.0	70.0	2	86.7
Chrome Vanadium	1,550 to 1,600	1,200	107,500	123,800	23.4	59.0	2	66.1
Chrome	1,550 to 1,600	1,200	77,875	99,375	24.2	68.5	2	68.1
Chrome Nickel	1,475 to 1,575	1,200	78,750	102,900	25.3	68.7	2	73.4

production, I would say that it forges entirely satisfactorily, with the particular advantage that the scale formed breaks away from the forgings very easily. With proper composition and for sizes within ordinary limits, it cold-shears as readily as the other grades of commercial alloy-steels. It responds very readily to the heat-treating operations, the percentage of forgings falling outside of the required Brinell hardnesses being very small.

With reference to its machining qualities, no figures can be given to corroborate the claims that have been made with regard to the reduction of tool costs and the like. In tests of this type, there is always doubt as to the exact uniformity of the tools performing the tests; also, the results obtained are very likely to be peculiar to a given shop and not be applicable universally. However, we have satisfied ourselves by noting the machinability of the tonnage that has passed through our shops that chrome-molybdenum steel machines at least as well as the best there is. We have not heard of a failure of any part made of this steel out of the 50,000 cars that have thus far been produced since its adoption.

Case-Hardening Grades

Approximately 90 per cent of the papers and information that have been published have referred to the forging or heat-treating grades of molybdenum steels such as are covered in the first portion of this treatise. Very few if any data have been recorded regarding the case-hardening grades, especially from the viewpoint of the consumer. Our first attention was to note whether any of the various grades of the low-carbon steels could be applied to case-hardened gears, knuckle-pins and shafts. The Studebaker Corporation is a large user of case-hardened gears and must demand the best commercial grade of steel for the purpose.

The chemical composition of the first heat experimented with showed carbon 0.130 per cent, manganese 0.400 per cent, sulphur 0.025 per cent, phosphorus 0.016 per cent, chromium 0.610 per cent and molybdenum 0.350 per cent. This analysis was abandoned for the reason that such high temperatures were required for double heat-treatment as would prove commercially impracticable. Quenching directly from the carbonizing box and using a single lower heat for hardening did not produce the desired results as regards core fracture.

The next step consisted in obtaining a higher-carbon steel to lower the quenching temperatures required and to find, if possible, a steel that would give the desired results by a single quenching temperature after carbonizing. The chemical composition of the heats obtained ran very consistently as follows: Carbon 0.190 per cent, manganese 0.540 per cent, sulphur 0.010 per cent, phosphorus 0.025 per cent, chromium 0.700 per cent and molybdenum 0.370 per cent.

The first tests made on the above analysis apparently warranted an extensive trial of this grade and, as a result, steel for 5000 cars was ordered. Upon getting into production with this material, with which all transmission parts and rear-axle gears and drive pinions were produced, certain peculiarities were noted that ordinarily could not be observed with a few trial test-pieces, the principal one perhaps being the fact that a satisfactory core fracture could not be obtained regularly; that is, after subjection to shock, the fracture would not show what is commonly called toughness but have a crystalline or granular appearance. This condition is particularly objectionable in parts that are subjected to a straightening operation and in clash gears. A further investigation proved that to obtain much better results, the part to be heat-treated had to be subjected to prolonged heating above the critical temperature of the core to bring about the proper condition before quenching and the lower heat for hardening had to be applied as quickly as possible to prevent the core from being subjected to lengthy heating at the lower temperature. This can be expressed more practically by stating that a certain gear, when heated for exactly 3 min. in a lead pot at 1425 deg. fahr. and then quenched in oil was a fairly satisfactory product; but, if held 4 min. or more in the lead pot at the same temperature, it became very brittle. This prolonged heating necessary above the critical temperature indicates, I think, a sluggishness peculiar to chrome-molybdenum steels and may account for the higher drawing-temperature permissible in the forging grades.

Effects of Carbonizing and Hardening

To indicate what happens in many cases to the core of this grade of chrome-molybdenum steel when subjected to the carbonizing and hardening treatment, Table 6 gives results of physical tests on pieces that were subjected to all of the heats of the case-hardening operations, they having been packed in sand for the carbonizing heat instead of in carbonizing compound.

TABLE 6—RESULTS OF PHYSICAL TESTS OF STEELS AFTER CASE-HARDENING[5]

How Cooled	Temperature of Quenching, deg. fahr.	Yield-Point, as Elastic-Limit, lb. per sq. in.	Ultimate-Strength, lb. per sq. in	Elongation in 2 In., per cent	Reduction of Area, per cent	Brinell Hardness No.
Quenched from Box into Oil	1,380 deg. Oil	57,625	102,625	9.30	22.00	212
		56,250	101,250	17.20	33.75	317
		57,750	90,250	25.00	53.25	189
		55,150	92,650	21.90	46.25	228
		70,250	105,250	14.10	30.50	206
	1,400 deg. Oil	63,875	108,875	6.25	4.00	228
		77,625	107,625	.....	.....	228
		64,000	109,000	14.10	22.50	241
		75,800	113,300	7.80	3.80	225
		67,050	109,550	14.10	27.50	228
Cooled in Box, 1,650-deg. Oil	1,425 deg. Oil	80,000	115,000	12.50	32.50	229
		85,000	120,000	12.00	31.00	235
		110,500	125,250	12.40	.....	252
		97,500	118,000	15.50	28.00	248
	1,425 deg. Water	120,000	136,000	7.00	Broke Outside Gage Marks	285
		100,000	110,750	4.00		269
		107,500	119,000	4.00	.....	248
		90,000	129,000	14.50	26.00	255

[5] All test-pieces ⅞-in. round were subjected to a 14-hr. heat at a carburizing temperature of 1650 deg. fahr.

It will be noted that a very peculiar combination of properties is obtained and we naturally are inclined to attribute the results we have obtained with case-hardened parts to these conditions. These properties do not exist with carbon-molybdenum, nickel-molybdenum or chrome-nickel steel of the same carbon-content. As to chrome-vanadium steel, I cannot comment upon it because all of this type that has been experimented with contains approximately 0.11 per cent carbon.

To obtain the best possible results with the case-hardened parts it was necessary, therefore, to quench from the carbonizing box into oil and follow this by the regular double heat-treatment and a final draw at 375 to 400 deg. fahr., timing each operation as carefully as possible. There are two particular advantages that should be noted, however, in that chrome-molybdenum steel will

(*Concluded on page* 62)

THE TRUTH ABOUT COMMERCIAL AVIATION

THE Section and Extension meetings that the Society has been furthering on Commercial Aviation have met with decided success. It was stated in announcing these meetings that an effort would be made to obtain speakers who would give the truth about commercial aviation. The remarkable attendance at all of the meetings thus far held is clear proof of the public interest in the subject and indicates the eagerness with which a program of real information is greeted. The public has apparently been waiting for some time for a progress report.

The Chicago Rotary Club requested the Society to include it in the program, and Glenn L. Martin, member of the Council, at the instance of President Beecroft, addressed the Club on Nov. 22. The audience was composed of a large number of Rotarians and guests. Mr. Martin stated that, although the operation of aircraft is undoubtedly costly as compared with slower forms of transportation, this will not appreciably retard the growth of aerial transportation since the airplane has the same relation to the railroad that a taxicab has to a street-car.

A committee comprising G. P. Dorris, chairman, G. F. Kublin, F. W. Gardner, J. A. Mummert and A. H. Timmerman, arranged a most enthusiastic dinner-meeting at St. Louis on Dec. 1. The speakers included Colin M. Selph, postmaster of St. Louis; A. B. Lambert of the Missouri Aero Club, F. W. A. Vesper and Past-President J. G. Vincent. On account of its geographical location, St. Louis is destined to be one of the great aviation cross-roads. That this is very thoroughly appreciated by St. Louisans was indicated by the presence of over 200 at the dinner.

Past-President Vincent's address on the Trend of Commercial Aviation, which is printed elsewhere in this issue, was a clear analysis of the economic possibilities of the airplane for commercial work. He indicated the factors now impeding the growth of aerial transportation as a business and suggested ways of overcoming these obstacles. Postmaster Selph spoke of the success of the air mail and urged the extension of this branch of the postal service.

Perhaps the most successful meeting of the series from the standpoint of attendance was that at Detroit on Dec. 5, when a dinner was given by the Detroit Section in conjunction with the Detroit Aviation Society and the Detroit Board of Commerce in honor of Admiral William F. Fullam, U. S. N., retired. Three hundred men attended the dinner and over 600 were present at the meeting that followed. Howard E. Coffin was chairman of the special committee on arrangements. C. F. Kettering was toastmaster. There are few toastmasters in what is now the dry-toast masticating business who are the equal of "Ket."

Speakers at the Indiana Section meeting on Dec. 12 included Past-President J. G. Vincent, V. E. Clark, chief engineer of the Dayton-Wright Co., Major Kirby and Lieut. McK. Robinson of the Air Service, T. A. Flaherty, secretary of the Hoosier Aero Club, and Charles Crawford. Nearly 100 attended the dinner. J. G. Vincent, in company with V. E. Clark and B. L. Whalen, flew to Indianapolis from Dayton, the trip taking 1¼ hr. In speaking of the best methods to be employed in developing commercial aviation, Past-President Vincent stated that the extension of the air mail service now being so successfully operated is of extreme importance.

The Metropolitan Section received so many applications for dinner on the occasion of its Aviation Meeting on Dec. 15 that it was necessary to turn away a number of members. Over 130 attended the dinner and nearly double that number were present to hear the speeches which followed.

Past-President C. M. Manly, who has been prominently connected with aviation for many years, presented an abstract of J. G. Vincent's paper on the Trend of Aviation and urged the desirability of using commercial aircraft at this stage of the development in such places and under such conditions as involve least competition with other methods of transportation. He pointed out the number of opportunities for the use of aircraft where other transportation media were not at hand and showed the comparative futility of attempting to compete at this time with short-haul railroad and other well developed means of transportation.

Ralph Upson, airship designer, who has recently returned from participation in the international balloon races abroad, spoke of commercial aeronautics in Europe. One of his remarks was to the effect that while in this Country people are looking upon Europe as the leader in commercial aviation, he had found that in England and in France the same attitude is taken toward American progress and that on the whole we do not suffer by comparison.

C. F. Redden, general manager of the Aeromarine Plane & Motor Co., spoke convincingly of the fact that commercial aviation has actually arrived and said that the problem is now largely one of inducing people to take advantage of the opportunities that are available for commercial flight. He mentioned that the cost per plane-hr. is slightly over $70, of which only about $15 is for gasoline and oil. A saving, therefore, of 25 per cent in engine efficiency, with a consequent reduction in cost of fuel of perhaps $4, would lower the total cost of transportation only slightly. On the other hand, since it costs approximately as much to fly a large machine with one passenger as with 10 an increase of the number of passengers actually carried on each trip would do a great deal in lessening the cost per individual. Mr. Redden spoke of the fact that travel by aircraft is more expensive than by any other means of transportation but felt that the higher rate would be paid by those to whom a saving of time is a matter of moment.

Com. H. C. Richardson, U. S. N., discussed the relation of civil aviation to National defense and called attention to the fact that while it is difficult to convert planes from war to commercial purposes or the reverse, it is comparatively easy to construct war machines in factories primarily equipped for the building of commercial aircraft.

S. H. Philbin outlined briefly the provisions of the Wadsworth bill, now before the United States Senate, for the control of civil aviation, and spoke of the need of fundamental legislation that is essential to the welfare of the aeronautic industry.

One of the largest meetings held by the New England Section since the time of its formation last year was convened at the Engineers Club in Boston on Dec. 16. Prof. E. P. Warner gave an address on the status of commercial aviation. Among the other speakers were President Roger Amory, of the Aero Club of Massachusetts, Major E. B. Lyon, aviation officer of the First Corps Area, both of whom stressed the need for a properly equipped landing-field near the center of Boston, and C. D. LeFevre, sections secretary of the Society, who gave an outline of Past-President Vincent's paper and told what had been accomplished in the interest of commercial aviation at other Section meetings.

An interesting feature of all of these meetings was the showing of moving pictures depicting the sinking of ex-German and obsolete American battleships by aircraft bombing. These pictures, which have not been publicly shown, are spectacular in the extreme and make obvious the vulnerability of even the most heavily armored ships to this method of attack.

President Beecroft at a luncheon given in his honor by the Aero Club of Sioux City, Iowa, on Dec. 8, gave an outline of some of the recent notable achievements in commercial aviation and spoke of the work that the Society is doing through meetings in the various parts of the Country in the interest of aviation. Mr. Beecroft gave an analysis of the Wadsworth bill for the control of commercial aviation which is now before the United States Senate, and emphasized the desirability of supporting this measure. He also presented a digest of J. G. Vincent's paper on the Trend of Aviation Development. An interesting part of his talk had to do with a description of the ground organization now being used in connection with commercial aviation in France.

If it had been possible to admit the general public to the

meeting of the Pennsylvania Section of the Engineers Club of Philadelphia on Dec. 22, a large part of the Christmas congestion of passenger and express traffic of the railroads would have disappeared. At least it is safe to say that the only reason for not using airplanes for fast service, would have been due to the lack of regularly scheduled airlines in operation and not to any doubt on the part of passengers or shippers as to the advantages of aerial transportation.

It seems almost incredible that the splendid results attained by the air mail should have received such scant publicity heretofore. Second Assistant Postmaster General Shaughnessy, who told Section members and members of the Aero Club of Pennsylvania about the air mail, quoted figures which indicate that astonishing progress has been made within the last few months.

In the 3½ years since the establishment of the aerial mail service 3,400,000 plane-miles have been flown, with 30 fatalities in the entire time. During the months of July, August and September of this year, however, the air mail has flown 391,000 plane-miles exclusive of test flights and has carried 10,014,000 letters. 97.5 per cent of the scheduled trips were flown on time. There were no injuries on regular trips during the entire period.

Ralph Upson spoke of European conditions and outlined the basis of the French and the English subsidies. He believes that subsidies based either on miles flown or on a percentage of the gross receipts tend to perpetuate whatever faults may now be present. He suggested that much greater good could be accomplished by granting prize money for improvements in design, economy of operation and night flying.

William B. Stout spoke of the requirements of commercial aircraft and emphasized the necessity for lowering maintenance costs through the use of all-metal planes in place of those having wood and cloth in their construction.

THE BUSINESS CYCLE

PRODUCTION and distribution are the biggest things in business, and production is first. Production can be divided into two classes, agricultural and industrial. Everything that is not agricultural production falls under the classification of industrial. Distribution, or marketing, depends largely on production. It is folly to study statistics of marketing because marketing shows the effect, not the causes. All through the matter of prognostication of the future, differentiate between the cause and effect. If we want to look ahead we have to figure the causes, and the effects will take care of themselves. We have four conditions; commodity prices, foreign trade, the railroad companies, transportation companies, carloadings and idle cars and then retail sales, four divisions of marketing.

The third classification is labor. We study labor under three or four heads; first, wages; second, controversy; third, immigration. The fourth division we call business profits, meaning by that the earning records of corporations. Then there are business failures; of course, they are just the opposite of business profits.

Next, we have new security issues, because the volume of new securities being offered reflects more or less how conditions are as far as business profits are concerned.

Fifth, we have exchange transactions; in other words, those transactions that take place on the commodity exchanges, on the stock exchanges and on the foreign exchanges.

The sixth division we call finance. Under finance we have bank clearings, bank statements, interest rates, gold movements between countries and operations of the United States Treasury Department.

Agricultural Production

The greatest thing in business today, the cause that has more effect than any other single cause upon fluctuation in business, is agricultural production. The thing that governs agricultural production will be the climatic conditions of the country, and who could pretend to foretell climatic conditions?

As far as the business cycle is concerned, you cannot tell from current agricultural production if we are in depression or prosperity. In other words, you find that the business cycle goes on regardless of agricultural production because the farmer is looking ahead and planning for his next crop, and at that time conditions may be entirely different. Industrial production, however, is at its lowest ebb in times of depression. We know it must be so because there is one thing that is making depression.

Do prices make business? Not always. Within the last year we had cotton at 42 cents, and we have seen cotton at 11 cents. Was it easier to sell cotton at 42 cents or 11 cents? At 42 cents. In other words, it is not the prices that determine whether you get the business or not. It is the trend of prices.

In the periods of depression, ordinarily speaking, exports tend to increase and imports tend to decline. Why? Simply because when prices are low here there is a foreign demand. Why are exports not increasing now? It is on account of the monetary situation in Europe.

Wages

Wages tend upward before labor conditions start to improve which is a peculiar feature. There is a tendency to put wages down to bed-rock, because expenses have been increasing during the preceding periods, and business has been falling off during the preceding period of liquidation. Wages get abnormally low. They get to the point where the worker cannot survive, and the employers have to increase the rates despite the fact that business does not justify it, and when they are doing that they are helping themselves, but they do not realize it. They say it is an added expenditure, and the profit is small. But with that increase to labor it does not need much to get business swinging back toward normal again, and the little increase that labor gets is one of the things that helps to bring it back.

Demand and Supply

The cause of the business cycle can be expressed very simply. It is simply the maladjustment between supply and demand. In the period of prosperity production is overdone. In the period of depression production is underdone, and sooner or later the demand will get ahead of the supply. If for no other reason than that production is underdone, it is psychological that when profits are large production is increased; when profits are small, or minus, production is curtailed. At some point it develops that there is a shortage. There is a demand for the given commodity, and the supply is not sufficient. The increase in business helps one industry here and another industry there. As the result of that the improvement spreads all through the business world.—D. M. Jordan in *American Machinist*.

Pertinent Facts Concerning Malleable-Iron Castings

By ENRIQUE TOUCEDA[1]

ANNUAL MEETING PAPER *Illustrated with* PHOTOGRAPHS AND CHARTS

ADDRESSING the structural engineer and the purchasing agent particularly, the author discusses the relationship between them and the foundryman with regard to malleable-iron castings and enumerates foundry difficulties. The characteristics necessitating adequate gating for such castings are described and illustrated, inclusive of considerations regarding pattern design, followed by a statement of the considerations that should influence the purchasing agent when dealing with foundrymen.

Possible casting defects are described, illustrated and discussed, comment being made upon casting shrinkage and machinability. Improvements in annealing-oven construction and operation are reviewed and the records of 100 consecutive heats in different plants are tabulated. The materials for casting that compete with malleable iron are mentioned and its physical characteristics are considered in some detail.

Emphasis is placed upon the necessity for the elimination of casting shrinkage and a brief summary is made of the most important features of the paper.

IN responding to the invitation to contribute an article covering the malleable-iron casting, I find no difficulty in determining the particular details which should prove of greatest interest at present to the user and manufacturer of these castings, because the two conditions that will be referred to overshadow in importance any others concerning which it would be possible to write.

It can be predicted safely at the start that the builder of automobiles, trucks or tractors is exceedingly anxious to use any product by which it is practicable to secure an increased output at less cost than possible through the use of some other material, provided the former were found to be equally dependable. On the other hand, the founder would be pleased indeed to market all the castings he could produce if this could be done at a reasonable profit. In short, it is but logical to assume that, under the conditions stated, there should exist between the two a mutual interest that should be continually strengthened, until modified if not nullified by the appearance of some other product equally reliable and less costly, or until such a time as the purchaser, in his desire to lessen the cost of his machine, shall be unable or no longer willing to pay a fair price for the castings.

It is in connection with this relationship that I would address those interested but, in doing so, I direct my remarks particularly to the structural engineer and purchasing agent; for, irrespective of how talented or how wide their experience with these castings may have been, there are certain facts that are difficult of ascertainment, either for or against them, short of an intimate experience in their manufacture, and it is but fair to assume that very few who have occupied either of these positions have had this experience. Unfortunately, the same can be said of the foundryman whose knowledge of automobile manufacture and construction is limited to the reading of his automobile catalogue and a perusal of the illustrations. While it happens that I am affiliated with a large number of the manufacturers of these castings, I am writing, as I have done invariably in the past, with perfect candor and with the concealment of no facts in connection with these castings that it would be to the interest of automotive engineers to know. This is true to such an extent that, as we proceed, I will present some details in connection with their manufacture and inspection that I trust will prove of value to the Society. In exchange, those who are striving hard to perfect their castings would like to count upon the business sympathy of the Society and the cooperative advice of automotive engineers in a serious work that, as stated, can correctly be considered in no other light than one of mutual interest, for it is my belief that, in the case of finished parts that are required to stand great abuse, there exists no other ferrous product of equal dependability that can be machined at anywhere near equal cost.

FOUNDRY DIFFICULTIES

It will facilitate my work if we consider for the moment a few of the various difficulties that confront the foundryman in various lines of endeavor. He may be working with a metal that it is impracticable to cast free from blowholes, even through the liberal addition of alloys that are introduced solely for the purpose of combining with the occluded gases. He may be using a metal that, even when surcharged with a high degree of superheat, is so sluggish when molten that mis-runs will be in order. The metal used may be one so sensitively weak at certain temperatures, after or during solidification, that contraction on the cores or between the gates may result in a prohibitive loss due to contraction cracks. The foundryman may be working with an alloy that must be made in accordance with strict specifications as to analysis, one of the component metals of which may be very volatile, with a resultant loss and the production of a casting of incorrect composition. The melting point of another metal may be so high that, when raised to a casting temperature sufficient to run the work successfully, even a very refractory molding-sand will burn on the surface and make machining costly. Difficulties are experienced with metals that segregate, lose their fluidity quickly, are drossy, crystallize out if poured in a sand mold, and the like.

In addition to the handicaps mentioned, whether the metal used is easy or difficult to cast, all founders are confronted with what is known as the molding problem in every instance. That this problem is replete with difficulties is certain, even when reduced to its simplest terms through the use of a metal almost ideally adapted to the making of castings with minimum risk of mis-runs, and that will cast true to pattern and with good

[1] M.S.A.E.—Metallurgical and chemical engineer, Albany, N. Y.

casting surface. In the case of air-furnace hard iron, the molten iron from which malleable-iron castings are made, molding difficulties are not occasioned because of the eccentricities of the metal, but the successful production of good castings is made both difficult and complex, due for the most part to the eccentricities of the pattern design. It must be manifest, if we are dealing with a metal the fusion point of which is lower than that of any metal suitable for the production of a ferrous casting, that owing to this low melting-temperature a minimum of occluded gases will be absorbed. If, in addition, the metal has carbon, silicon and phosphorus contents so high as to yield a fluidity sufficient almost to pour needles, it is evident that something must be radically wrong if the castings are not only free from blowholes but from shrinkage as well. So far as the former trouble is concerned, when blowholes are present in a malleable-iron casting, which I believe the user will acknowledge is infrequently the case, it almost invariably is the fault of molding practice. It is due to sand that is too damp or too tightly rammed, to cores that are too compact or badly vented, or to similar causes, and rarely if ever due to occluded gases. On the other hand, when shrinkage occurs, and this is one of the most harmful and disastrous imperfections that can be present in a malleable-iron casting for reasons that will be entered into later, while the fault at times may be due to bad molding-practice, it can be stated safely that in by far too many cases the structural engineer has furnished a design that cannot be produced entirely free from this defect, even through the exercise of the highest degree of molding skill and the use of much extra metal in the form of risers and heads, the subsequent remelting of which is costly.

Adequate Gating

For molten metal to fill a void, it must not only have free entrance to it, but the entrance must be proportioned so as to admit of the void being filled completely before the entrance or, as it is commonly called, the gate, becomes closed by the gradual solidification of the metal passing through it. Let us assume that these conditions have been almost but not wholly fulfilled in the case of a void of very simple character, for example, that made by a small rectangular block, and that the metal in the gate has frozen prematurely so far as the conditions stated are concerned. In this event, while the surface of the casting will be a true replica of the void design, as must happen by reason of the fact that the molten metal as it enters the void and strikes the cold surface of the sand will freeze instantly into a very thin solid shell of similar form, there will not be a sufficient amount of molten metal present to produce a perfectly sound casting, because molten iron occupies more space than solid iron. Under these circumstances it will be found that a shrinkage or cavity will exist in the casting of a size dependent upon how much too soon the metal in the gate or void-entrance solidified, thus preventing the casting from being furnished with sufficient molten metal as solidification was progressively taking place. A hole may result in exaggerated cases, or an area of greater or less dimensions and of greater or less porosity may be produced if conditions are less bad.

Let us assume that the conditions first referred to were fulfilled as described, and that the metal in the gate and in the void freeze simultaneously. Even under these conditions a very imperfect casting will be produced, because if metal occupies less space when solid than when molten, sufficient metal still will be lacking and, in consequence, a porosity will exist that will be proportional to the metal deficiency. It is clear, therefore, that to produce a sound casting of this character it is not only essential that the metal in the gate or void entrance remain fluid for a sufficient length of time to enable the void to be filled, but provision must be made for the metal in the gate to remain fluid until after that in the void has solidified completely, in order that, as solidification in the void progresses, no cavity can remain by reason of lack of fluid metal to occupy its space continually to the vanishing point. The basic principles of pattern design and subsequent molding call for a pattern proportioned so that it is possible through the exercise of skilled molding-practice to gate and head the pattern so that the molten metal will feed to all its parts as they progressively solidify from the surface inward as the volume change takes place. When the molder's skill is exhausted and shrinkages still appear, it is not unreasonable to conclude that the pattern design should be changed.

Pattern Design

To illustrate a very important and fundamental fact to those who have to do with the design of patterns, the following simple illustration will suffice. Let us consider the case of a casting consisting of two rectangular parts of equal dimensions connected together by a rectangular member of considerably smaller cross-section, the overall size of the pattern being such that four can be placed in one flask. If gated at one end, the metal will flow in the rectangle to which the gate is attached, thence through the thin section and from it to the other rectangle. Under these conditions the entire casting must be fed from the gate as gradual solidification progresses, because molten metal can, in this case, be derived from no other source. It is certain that, when thus cast, the rectangular part farthest from the gate will be more or less unsound, for it is hardly to be expected that the small gate at one end can feed the rectangle farthest from it continuously, owing chiefly to the more rapid solidification of the metal in the much smaller section joining the two heavier parts.

Actually, this thinner section will be drawing metal from the two larger connected parts, for the metal in these will act as reservoirs to feed it and, in doing so, make certain their own unsoundness, particularly in the case of the part farthest from the gate. In order that the latter be made solid, it is essential either that the metal in the thin section be kept fluid a sufficiently long time to provide that part with a continuous supply of molten metal until its solidification is complete, or a head or reservoir must be placed upon it from which it can obtain an auxiliary supply independently of the thin part to which it is attached. However, in castings of intricate design which, in automotive castings, is the rule and not the exception, it is frequently impossible for mechanical reasons to furnish independent heads or reservoirs to each disproportionate part, and it is essential therefore that balanced solidification through a possible feeding of every part be facilitated by a proper pattern design, coupled with skilled molding-practice. To make success possible, the founder gates and heads his castings in such a manner that the feeding of the heavy parts will be accelerated to such an extent as is possible, but how often is the design such that, in spite of every expedient known to the skilled molder and of the use of a metal of the very best casting characteristics, an absolutely sound casting cannot be made For the sake of his reputation and for the good of the industry, the founder

should have the courage to refuse to use patterns from which a product free from shrinkage cannot be made.

Foundry Policy and the Purchasing Agent

In the case of a certain casting, let us assume that, through the exercise of great molding skill, the most favorable gate emplacement and correctly placed risers that jointly will weigh considerably more than the casting, it is found that solidity can be secured through use of these costly expedients. Let us assume further that the purchaser has decided to obtain these particular castings from three sources of supply. Founder No. 1 is conscientious and, through the use of very high and bulky heads and risers, is furnishing a perfectly reliable casting. Founder No. 2 is less careful and some minor shrinkage is present in his castings. Founder No. 3 is still less careful and his castings fail in service. Does the purchasing agent or the engineer analyze the situation and condemn the particular source from which these castings came, cancel the order and transfer it to Founder No. 1; or, does he suggest that the malleable casting is not to be depended upon and recommend that

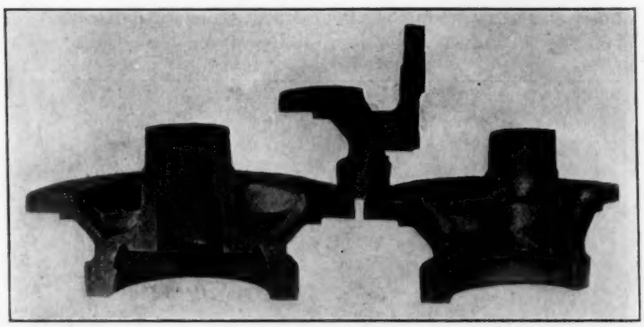


Fig. 1—Sections of a Gear-Case Showing Solid Metal in the Left Portion and a Minute Amount of Shrinkage at the Right

another metal be substituted for it? If the product were apples, it is certain that at least one source of supply would be dropped because the purchaser knows a good apple on sight and that good ones are purchasable. If apples are the fruit he wants, he would be considered somewhat eccentric if, on account of having received bad apples from one source of supply, he cancelled the order with the other two sources and decided to substitute pears for apples.

The foregoing may seem far afield as a parallel case, but it appears to me to be entirely analogous. The automotive engineer has need of good malleable-iron castings because of their wonderful machinability and ability to stand great abuse in service and, should some castings fail in service, it is hardly fair to conclude that the trouble is fundamentally with the metal per se, when as a matter of fact it lies with the source of supply. The conditions referred to are exaggerated, owing to the attitude of the purchasing agent. In his perfectly legitimate desire to do the best possible for his company, he often mistakenly places price ahead of quality. We have good automobiles and we have poor ones, which fact should not condemn the automobile. In just the same manner as an automobile salesman would laugh at the man who wanted a high-grade car for the price of a fliver, the competent and conscientious malleable-iron founder should be excused if he smiles when asked to meet the price of a competitor who, instead of using the costly expedients that have been shown to be necessary to secure soundness, will ship castings that in general

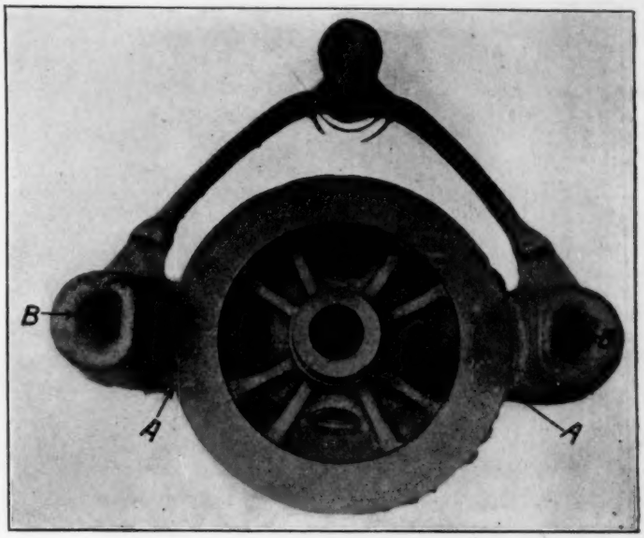


Fig. 2—View Looking Down on a Gear-Case Casting with the Gates and the Risers Attached

appearance are all right but which close inspection will disclose are unsound. In the case of two sources of supply, all costs being alike in both cases except that for molding and extra metal used in risers and heads, there easily can be a difference of 2 cents per lb. in the cost of production between a casting that is perfectly sound and one that is nearly so. I recommend that, in the purchase of malleable-iron castings, the source of supply be given the weight that its importance deserves, particularly until the designing engineer awakens to the necessity of a fuller cooperation with the founder.

Let us assume that the engineer has decided to substitute another product in lieu of the malleable-iron castings. No risk will be taken in making the statement that, before the contract is signed by the vendor, he will request that he be granted permission to alter the pattern that was furnished and used by the malleable iron founder. The request will be made that he be allowed to thicken the sections here and there, that certain corners be replaced by generous fillets and other modifications such as in his opinion will better adapt the pattern to the peculiarities of his particular metal. I have no quarrel with the reasonableness of this request, because it is absolutely along the lines of commonsense, but in the majority of cases permission will be granted in such cases that strenuously was denied the malleable-iron founder, and, while I can offer no explanation for this curiously illogical situation, I can vouch for the accuracy of the statement.

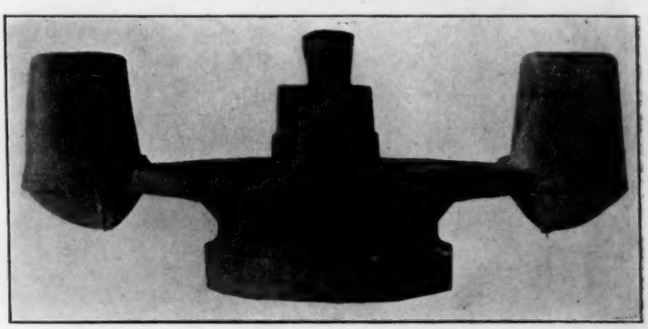


Fig. 3—Side View of the Gear-Case Casting Shown in Fig. 2 Before the Gates and the Risers Were Removed

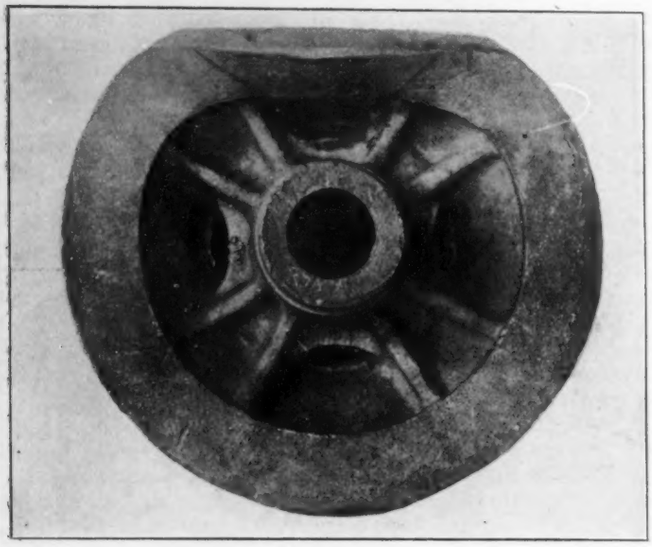


FIG. 4—A GEAR-CASE THAT WAS DEFORMED BY SLEDGING TO DEMONSTRATE THE DUCTILITY OF THE METAL

POSSIBLE CASTING DEFECTS

To illustrate in a practical manner some of the statements that have been made, we will consider Fig. 1, in which various sections cut from a gear-case shown in Figs. 2 and 3, two views of this casting with gates, runners and risers attached, can be seen. In Fig. 2 the large size of the gate at *A* should be noticed; it is so large that it is with difficulty that it can be broken off without disfiguring the casting. I also would call attention to how efficiently the heads have served to feed the casting during solidification, for the cavities at *B* in these heads practically are a direct measure of the amount of metal they supplied to the casting during its solidification period. The use of such large gates is possible owing to the introduction of a strainer core set at the bottom of the pouring sprue that serves to take care of the dirt and thus make possible gate enlargement. These heads, runners and sprues jointly weigh considerably more than the casting. In Fig. 3, the massive heads with large wells below gate level, made in this manner in order that the metal in the gate will not prematurely freeze but remain open until the solidification of the casting is completed, should be noticed.

Let us now take up the lesson that can be drawn from a consideration of the sections shown in Fig. 1. It can be seen in the full half-section that one side of the casting is absolutely solid while there are two shrinks in the other side that are so small and so located that their presence would not affect the strength of the casting in such a manner as to cause it to weaken or fail in service. The section is shown, however, to illustrate how delicately balanced are the conditions that make for shrinkage or its absence. Here is a case where a casting is gated in very generous fashion, with heads that weigh more than the casting itself and are symmetrically placed; and still one side of the casting is perfectly sound while a small shrinkage is present in the other. The reason is simple. In spite of the precautions that have been taken in the use of large gates and high and bulky feeding heads symmetrically placed, a little slower feeding occurred on one side than on the other. The pattern is intricate and a slight difference in friction or in the division of the molten metal on reaching the bottom of the pouring sprue could cause the slightest difference in the rate of feeding of the two sides in a case where such extreme measures had to be taken to insure soundness. But, should a pattern be designed so that it is essential to have to go to these extremes to make soundness certain, if it is easily possible to design it in the first place so that casting difficulties are absent or, having designed it incorrectly, is it not best at least to make the slight changes that would improve the casting condition?

I venture to state that if, without changing the total weight of the casting in question, the founder were per-

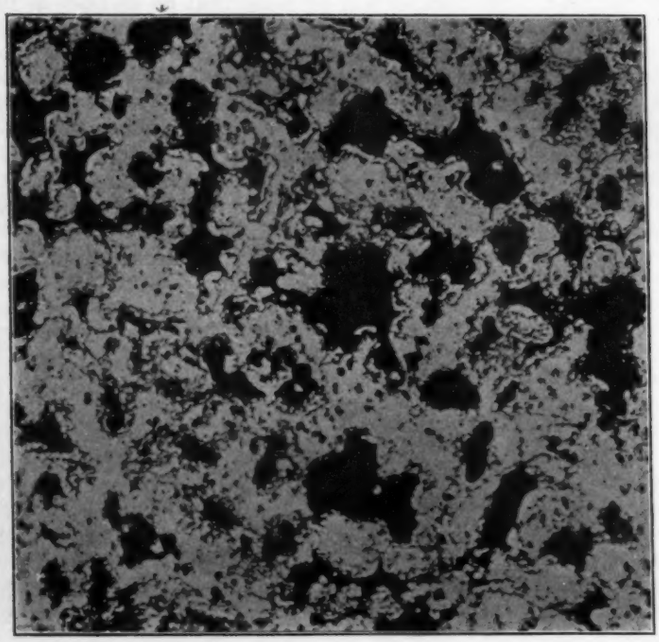


FIG. 5—PHOTOMICROGRAPH MAGNIFIED 150 DIAMETERS SHOWING THE STRUCTURAL CONDITION EXISTING IN A SHRINKAGE

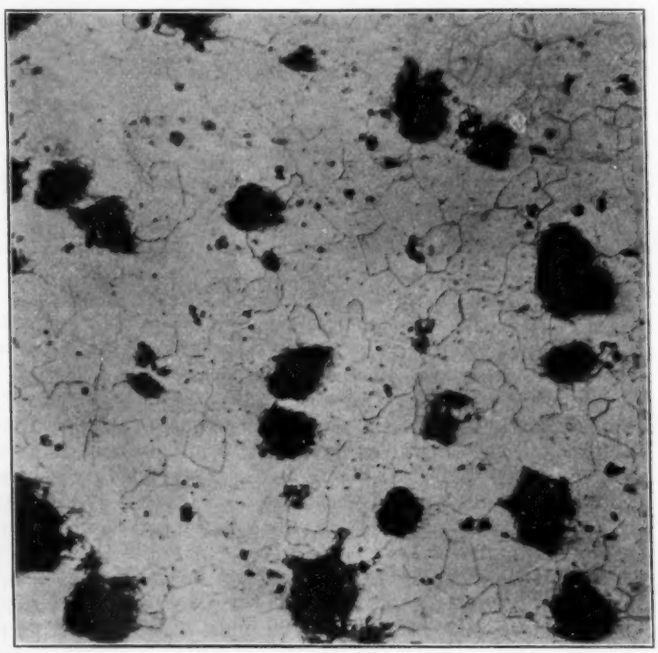


FIG. 6—PHOTOMICROGRAPH OF A NORMAL PORTION OF A CASTING ADJACENT TO THE SHRINKAGE ILLUSTRATED IN FIG. 5, MAGNIFIED 100 DIAMETERS

mitted to alter the thickness of certain sections at two places by an extremely small margin and deduct this weight from the heavier parts where it can be proved easily that a small amount of useless metal exists, not only would there be no unsoundness at any locality, under the present system of molding, but this result invariably could be accomplished with certainty and with considerably less waste metal. In considering the foregoing, the engineer should keep in mind at all times that air-furnace hard iron, next to gray iron, is the easiest of all ferrous metals to cast. What these particular castings are capable of enduring can be seen by reference to Fig. 4, which shows one that has been sledged down and deformed to a considerable extent.

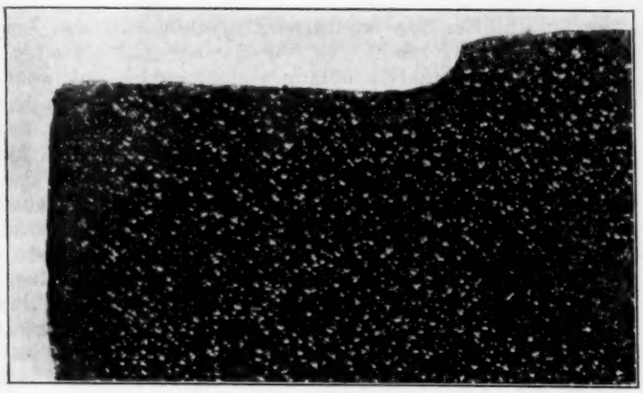


FIG. 7—PHOTOGRAPH WITH VERY LOW MAGNIFICATION OF A CASTING THAT IS HARD THROUGHOUT BUT HAS THE HARDEST METAL AT THE SURFACE

Let us take up another phase of the shrinkage problem and make plain a most important matter; one that perhaps is not fully appreciated by the engineer or the inspector. In the case of the shrinkages in the castings we have just considered we have concluded that, as located and in view of their small size, they would not cause the castings to fail in service. Let us assume that the same statement would hold true if a minute shrinkage were located at some point where machining would be required. In this case, however, much damage could be caused, for shrinkage is really synonymous with hardness. Contrary to the opinion of some, the hard spot due to segregation is not an evil inherent in the malleable-iron casting. A moment's thought should convince the engineer of this fact, for the sections are so thin that solidification takes place too quickly to admit of this trouble. When a hard spot occurs in a malleable-iron casting, it invariably will be found that it is due to the presence of a shrinkage, a matter that I demonstrated very early in my investigations. Therefore, it can be accepted as a fact that heavy losses can be sustained by the manufacturer if even slight shrinkages occur near surfaces that have to be machined.

MACHINABILITY

In the micrograph reproduced in Fig. 5 the structural condition existing in a shrinkage can be seen. This should be compared with that of the sound and normal metal adjacent to it that is shown in Fig. 6. For reasons not fully understood, free cementite, the hardest constituent that can occur in iron or steel, usually is associated with a shrinkage area and it is to this constituent that the hardness is due. That shrinkage is a defect that should not be tolerated in a casting is true. The purchaser should, through rigid inspection, safeguard

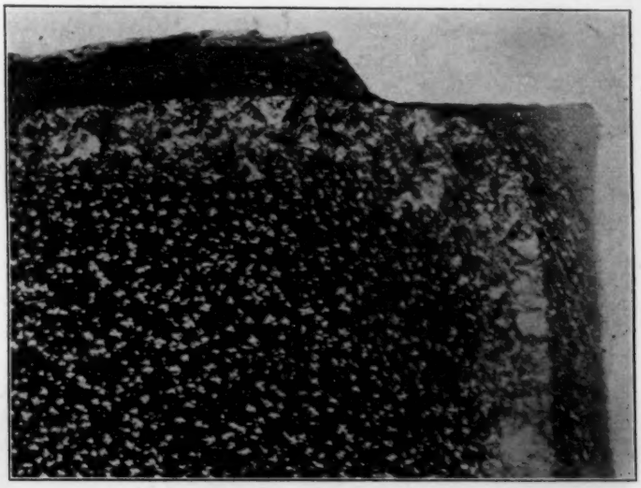


FIG. 8—A VERY LOW-MAGNIFICATION PHOTOGRAPH OF A CASTING THAT WAS HARD TO MACHINE ON ACCOUNT OF A HARD INNER BORDER OF PEARLITE BETWEEN THE SURFACE LAYER AND THE SOFTER METAL UNDERNEATH

himself in this particular, but he should approach this trouble with tolerance and contribute his share toward eliminating it. It is unreasonable that the founder be required to bear the entire burden if the dominant part actually rests on the shoulders of another. On the other hand, when castings are received that are hard to machine for reasons other than shrinkage, the fault can be wholly attributed to the founder. Such conditions can be occasioned even in the case of castings of ideal composition due to various causes, through failure to anneal them at a high enough temperature for a sufficient length of time, by too low an annealing temperature or by a too rapid rate of cooling, in all of which cases the castings will be uniformly hard throughout. Such a case is shown in Fig. 7.

Castings may prove hard to machine due to a surface hardness that usually is occasioned by an unbalanced sulphur-manganese ratio, particularly when this condition is accompanied by too high a temperature of anneal, the condition being worse the higher the temperature becomes. Figs. 8 and 9 illustrate this condition. The

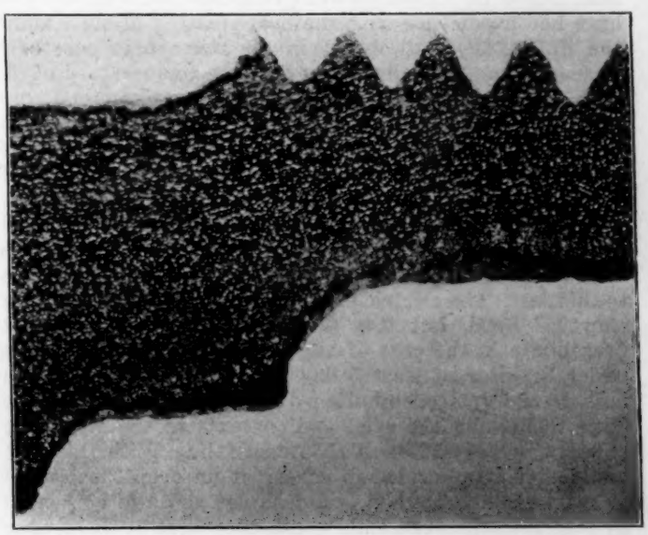


FIG. 9—PHOTOGRAPH WITH VERY LOW MAGNIFICATION OF A PIECE HAVING A HARD SURFACE TO MACHINE

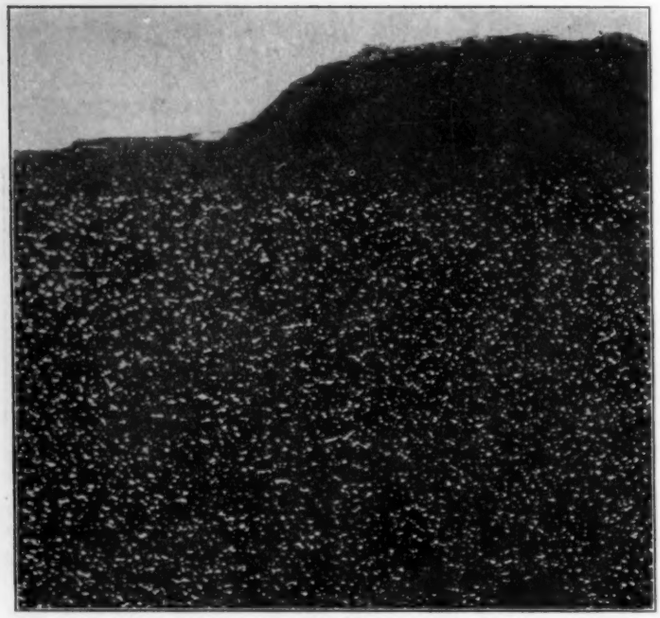


FIG. 10—A VERY LOW-MAGNIFICATION PHOTOGRAPH OF A CASTING HAVING A DEEP AND THOROUGHLY DECARBONIZED SURFACE BORDER THAT WAS VERY SOFT AND CONSEQUENTLY DEVELOPED CUTTING-HARDNESS

same trouble can originate when the silicon, manganese and carbon contents are unduly low; or, what can be termed cutting hardness can obtain when the castings have undergone such a complete surface-decarbonization that the surface metal is hard to machine owing simply to its very softness that gums the tool and creates a friction that quickly draws the hardness of the tool cutting-edge. Fig. 10 illustrates this. In any and all such cases, and there are others that have not been mentioned that can cause surface hardness, the responsibility for the trouble lies entirely with the founder. I will endeavor to make clear that trouble from such occurrences soon will be a thing of the past.

ANNEALING-OVEN IMPROVEMENTS

For the past 4 or 5 years a gradual improvement has been made in annealing-oven construction. Those who have had experience with the heat-treating of steel know the difficulties that obtain in an attempt to construct an oven of even small size so that the temperature at all parts can be kept uniform and under satisfactory control. It will be admitted, that the problem is increasingly difficult, the larger the oven is and, in the case of such large ovens as are required for the annealing of 30 to 60 tons of bulky castings, the difficulties are great. In spite of this, coal-burning ovens have been constructed that have proved to be surprisingly satisfactory, and the improvement in product is due in considerable measure to this fact. The electric oven for heat-treating is nothing short of ideal, but this proposition has been thought prohibitive in the case of very large ovens that must be under heat for at least 5 days. It is manifest that the bulk of current consumption during an anneal will take place in heating the oven and contents to the annealing temperature of 1525 and 1550 deg. fahr. With this fact in mind it was decided to construct an oven that would be insulated thoroughly, and designed so as to be heated by coal until the oven and its contents were at the proper temperature, the remainder of the anneal being accomplished by electrical heat under positive control. This has been done and coal is used only in raising the oven and its contents to the annealing temperature. As soon as this has been attained, the current is turned onto the resistance ribbons automatically, and from this time on they are kept at a constant temperature through thermometric control, which is also used in lowering the temperature in accordance with the rate desired. Through this procedure the annealing problem, that heretofore has occasioned more than considerable anxiety, has been converted into a foolproof proposition that actually will take care of itself automatically in every case. Even through such an expedient it is still possible that some hard castings will be produced, but this can happen only in the event that the castings charged in the oven are of incorrect composition; but it will be shown later that the possibilities for occurrences of this kind are continually growing less.

With the elimination of annealing troubles the industry will have taken its longest step forward, the importance of which should be plain to all. That I am justified in the statement that the danger of faulty composition is but slight in the case of many of the plants, and that uniformity of product is very consistent and under good control, can be shown by consideration of the record of some of the plants. The performance is not confined to one or two, but is attained by a large number of them. It is true that not all of the plants have arrived at this point of excellence. This paper was prepared in part to illustrate briefly just what has been achieved in the way of progress and what may be expected in the natural course of events. Every difficulty that has been encountered has been fought to a finish insofar as money, time, hard work and available knowledge have made this possible; and as soon as it was felt that any particular problem was solved, work was started toward getting each plant in line. This procedure has been, and is, slow, but it is sure and, if the improvement thus far shown can be relied upon as indicating anything at all, the conclusion safely can be drawn that, with continual striving and persistent effort, the malleable iron casting should feature strongly in automotive construction.

TABLE 1—TEST DATA FROM 100 CONSECUTIVE HEATS

Plant	A	B	C	D
Ultimate-Strength, lb. per sq. in.	55,203	54,442	53,483	52,813
Elongation in 2 In., per cent	20.21	17.30	19.85	16.24
Best Bar Based on Ultimate-Strength				
Ultimate-Strength, lb. per sq. in.	60,678	59,500	57,397	56,900
Elongation in 2 In., per cent	27.50	19.00	28.90	17.00
Best Bar Based on Elongation				
Ultimate-Strength, lb. per sq. in.	58,180	57,000	55,833	53,800
Elongation in 2 In., per cent	31.50	28.10	31.50	27.00
Poorest Bar Based on Ultimate-Strength				
Ultimate-Strength, lb. per sq. in.	49,000	48,000	47,001	46,700
Elongation in 2 In., per cent	9.40	12.00	11.71	10.00
Poorest Bar Based on Elongation				
Ultimate-Strength, lb. per sq. in.	49,000	57,000	50,488	46,800
Elongation in 2 In., per cent	9.40	10.90	9.31	7.50

The records of 100 consecutive heats in the case of several of the different plants are tabulated in Table 1. It is believed that these data are sufficient to indicate at least that more than reasonable uniformity and efficient control are possible and practicable. While I trust that the points already covered will be looked upon as pertinent and of interest, I have not lost sight of the fact that what the engineer particularly desires to have is specific facts of such a character as will enable him to decide to what extent he will be justified in using the malleable-iron casting in the construction of his machine. It is realized also that he desires this information free from bias or misrepresentation.

Competing Materials for Casting

I am fully aware of the present shortcomings of the malleable-iron casting and of the materials that enter into competition with it. I know the latter as thoroughly as I believe I understand the shortcomings and merits of the product of which I am writing. In the case of one of the competitive products the serious difficulty is in connection with blowholes and poor machinability; in another case the fact that there may be unreliability because the finished article is but a very small part of a huge mass of metal in which segregation is possible and in which serious unsoundness not ascertainable except by the destructon of the part may be present and undiscoverable until failure takes place, is coupled with the difficulty of poor machinability; in a third product, which is an excellent one, the chief shortcoming is its limitation in regard to the form in which the article can be produced. These statements are set forth with but one idea in mind, to bring out the point, with which all are familiar, that in no case can any product be made perfect, nor does any single product possess all of the merits that are desirable. In the case of the three competitive products mentioned, all of which consist of steel, no doubt exists in the mind of the automobile engineer as to the fact that the metal per se is excellent in those cases where the composition is all right and structural imperfections absent. However, the source of supply is a matter that must be considered in connection with these products also, although I believe that at present this is not true to the extent that obtains in connection with the malleable-iron casting, for which reason, as has been pointed out previously, it is absolutely essential that this particular matter be given proper and painstaking consideration if these castings are to be used. It has been inferred that in the case of the three competitive products the engineer is fully satisfied with the metal from which they are made, because the metal is steel, and it is known that good steel is excellent, but the fact is often overlooked that the quality of steel, in common with all other products, may be inferior.

Physical Characteristics

Let us consider fully those physical characteristics of malleable iron with which the engineer is chiefly concerned. In Fig. 11 two different sets of curves are shown. The top curves cover ultimate-strength in pounds per square inch and the lower ones the percentage of elongation in 2 in. The broad line indicates in each case the requirements of the American Society for Testing Materials, and the curves above these show respectively the average ultimate-strength and the elongation of some 70 different plants. An inspection of these curves will demonstrate the fact that for nearly 4 years both the average ultimate-strength and the elongation of the bars of the plants referred to have been far in excess of the

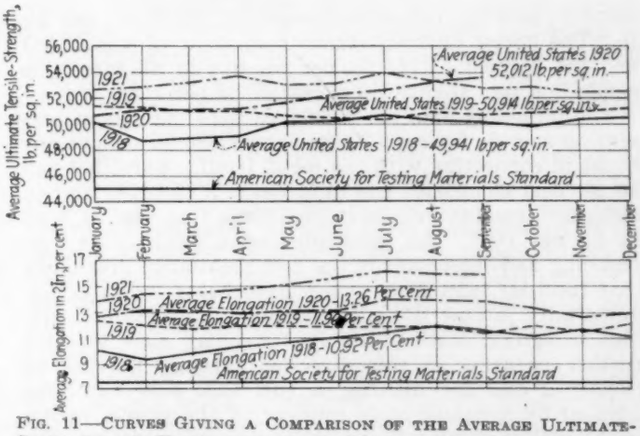


FIG. 11—CURVES GIVING A COMPARISON OF THE AVERAGE ULTIMATE-STRENGTH AND ELONGATION OF THE CASTINGS PRODUCED BY SOME 70 MALLEABLE-IRON FOUNDRIES FROM JAN. 1, 1918, TO SEPT. 1, 1921, AND THE REQUIREMENTS OF THE AMERICAN SOCIETY FOR TESTING MATERIALS

American Society for Testing Materials requirements. The curves indicate also the healthy progress that has taken place from year to year under conditions that at times have been rather trying, in that frequently during this period it was impossible to secure the materials best suited to the process. For the past year the plants have not operated except at very low capacity, under which condition it is most difficult to operate with the ease that is possible when the plants are running at or near capacity.

While these curves apparently indicate truly the actual progress that has been made, what they show is misleading in that they are representative of the progress that has taken place among these plants with an increase in membership. A truer measure of progress could have been shown if the results of the original 20 or more plants that first formed the body in question had been plotted. The reason for this statement lies in the fact that the curves have been influenced continually by the taking in of new plants, the records of which at the start and for some time afterward obviously have served to lower the average record of the entire body. To present an accurate idea of what certain individual plants are doing and have done consistently for a long time, I will quote from my last report to this group of plants, which covers bars cast during the month of September, 1921.

TABLE 2—AVERAGE ULTIMATE-STRENGTH AND ELONGATION OF TEST BARS AT 14 PLANTS FOR SEPTEMBER, 1921

Plant	Ultimate-Strength, lb. per sq. in.	Elongation in 2 In., per cent
A	59,976	21.45
B	59,500	19.34
C	58,945	19.73
D	56,314	19.78
E	56,088	22.03
F	56,030	19.72
G	55,838	19.65
H	55,519	20.33
I	54,929	19.29
J	54,758	23.00
K	54,373	23.40
L	54,107	23.62
M	53,699	19.11
N	50,605	20.26

The average ultimate-strength and elongation, respectively, of 14 different plants for bars cast during this month are shown in Table 2. In this same month there were eight other plants in which the bars collectively

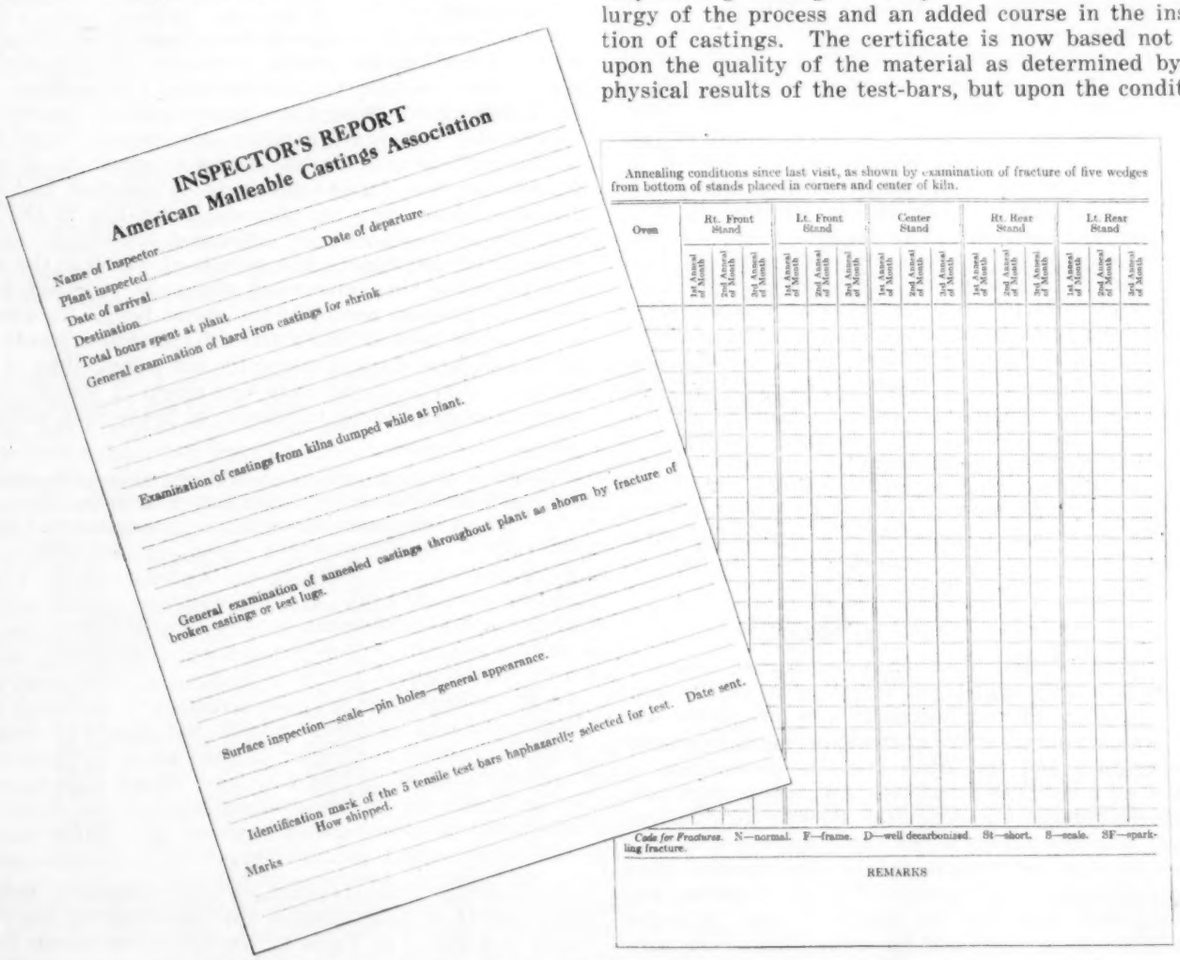
stood at average ultimate-strength of 55,137 lb. per sq. in. The lowest ultimate-strength in any case was 52,511 and the highest 57,774 lb. per sq. in.; in all cases, the elongation was slightly in excess of 18 per cent.

The foregoing data are furnished with the idea of presenting specific figures. These figures should remove any doubt in connection with the metal itself. Bars that run 30 per cent elongation are in no sense a surprise, and on different occasions we have had some that ran as high as 35 per cent. An accomplishment much more far-reaching and important is the fact mentioned previously that tests on bars from consecutive heats indicate that uniformity is now the rule and not the exception. Recent investigations indicate that we may hope for still further progress in this direction through the use of powdered coal for melting, a fuel that now has been adopted by a considerable number of the plants, owing to the ability of adjusting combustion and oxidation conditions with greater refinement. It is believed that, so far as uniformity is concerned, conditions will continue to improve. Remarks have already been made in connection with the annealing process and the steps that have been taken to safeguard this important end of the proposition.

Elimination of Shrinkage

While they are of prime importance, the concern of the producer of malleable-iron castings today is not in connection with uniformity and annealing, but is directed almost wholly to the matter of the elimination of shrinkage. Much has been learned as to the most efficient methods of gating and of heading the castings to insure soundness. The assistance of automotive engineers in this direction is needed and should be given unstintingly. Some automotive engineers may not be aware that it was decided several years ago to issue a certificate to those plants in which the test-bars for the month were equal to or better than the requirements of the specification of the American Society for Testing Materials. It soon was discovered that some of the members who were able to qualify in this connection were shipping castings that were defective owing chiefly to the presence of shrinkage, or that were hard to machine at high speed.

While the test-bar records of heats certainly have served a most useful purpose and are indispensable, it was seen clearly that the issuing of a certificate should be based not only upon the quality of the metal per se but that steps should be taken to put into force some method whereby the soundness of the casting could be assured, in order that the final granting of the certificate would be dependent upon the integrity of the castings as well. With this end in view it was decided to establish an inspection bureau that would form part of the engineer's office, the sole duty of which would be to send inspectors to the various plants to report to his office the exact conditions at each plant in regard to castings hard to machine and that contained shrinkage or other defects. Technically trained men were selected for this purpose, they having been given a special course in the metallurgy of the process and an added course in the inspection of castings. The certificate is now based not only upon the quality of the material as determined by the physical results of the test-bars, but upon the conditions



INSPECTOR'S REPORT
American Malleable Castings Association

Name of Inspector ..... Date of departure .....
Plant inspected .....
Date of arrival .....
Destination .....
Total hours spent at plant .....
General examination of hard iron castings for shrink .....

Examination of castings from kilns dumped while at plant.

General examination of annealed castings throughout plant as shown by fracture of broken castings or test lugs.

Surface inspection—scale—pin holes—general appearance.

Identification mark of the 5 tensile test bars haphazardly selected for test. Date sent.

Marks ..... How shipped.

Annealing conditions since last visit, as shown by examination of fracture of five wedges from bottom of stands placed in corners and center of kiln.

Oven	Rt. Front Stand			Lt. Front Stand			Center Stand			Rt. Rear Stand			Lt. Rear Stand		
	1st Anneal 2nd Month	2nd Anneal 2nd Month	3rd Anneal 2nd Month	1st Anneal 3rd Month	2nd Anneal 3rd Month	3rd Anneal 3rd Month	1st Anneal 3rd Month	2nd Anneal 3rd Month	3rd Anneal 3rd Month	1st Anneal 3rd Month	2nd Anneal 3rd Month	3rd Anneal 3rd Month	1st Anneal 3rd Month	2nd Anneal 3rd Month	3rd Anneal 3rd Month

Code for Fractures. N—normal. F—frame. D—well decarbonized. St—short. S—scale. SF—sparkling fracture.

REMARKS

Fig. 12—Views of the Front and Back of an Inspector's Report Blank

at the plant in regard to the soundness and hardness of the castings.

The completeness with which the inspectors' work must be done can be gathered from Fig. 12 in which the obverse and reverse sides of the form which they are required to fill in are reproduced. I believe that the provisions contained in this inspection form cover the ground in a complete manner. If the castings of any plant are shown on one of these reports to contain shrinkage, not only is the matter taken up from this office but it is thoroughly ventilated at the plant itself. It can be conjectured that since the adoption of this procedure the quality of castings shipped has improved greatly. While this obviously has added somewhat to the cost of production, the sum, large as it is, is rather inconsequential as compared with the increased cost that has resulted through the attempt to eliminate shrinkage. Some time ago it was not unusual to obtain 75 per cent of castings from an air-furnace heat, whereas today in most of the plants referred to this figure is about 50 per cent, because of the large heads and risers used. Not only has the cost of remelting, extra cost for sand and the use of larger flasks been increased in consequence, but it is clear that air-furnace capacity has been lowered enormously.

Summary

In conclusion, the engineer need feel no anxiety in regard to the metal that enters the castings for, in this particular, there is absolutely no question whatever but that we have arrived. On the other hand, he should be very watchful in connection with such unsoundness as may result from shrinkage. The defects, if present, will be found generally where sections change abruptly from thin to thick; also at heavy bosses, where slight defects obviously will do absolutely no harm unless the boss is to be bored, when they will occasion much trouble in machining. Hard spots do not result from segregation, but from shrinkage. Blowholes, when present, are rarely if ever occasioned by occluded gases, and they are of rather infrequent occurrence due to any cause. There is only one case in which castings are hard to machine that the trouble has resulted from lack of annealing temperature or time at that temperature or from too rapid cooling, and this is when the casting is hard to machine throughout. In all other cases when castings are hard to machine, it will be found that the trouble is due to the presence of a more or less hard surface skin that may be produced in other ways than through lack of temperature during the anneal, lack of time at the annealing temperature or too quick cooling. It will be found that beneath this surface skin the metal is soft. This trouble, as previously pointed out, results in the greater number of cases from incorrect composition, the evil effect of which will be exaggerated by too high a temperature of anneal. At times, this trouble can result from a casing of the surface through a temporary pot atmosphere that is strongly reducing.

A deep and very soft decarbonized skin also can cause trouble in machining, due to its very softness. It is anticipated that all characters of machining trouble mentioned will disappear with the general installation of the electric annealing methods alluded to, although this in turn will result in an increased cost of production. It has been shown that little fear need be anticipated concerning a reasonable uniformity in physical properties of the metal from heat to heat.

Air-furnace construction and melting and the source of heat are being given every possible consideration. In a considerable number of the plants, carbon-dioxide recorders have been installed and if within a reasonable period it is found that this will contribute toward greater uniformity, these will be adopted generally.

First and foremost consideration should be given the source of supply. Be very suspicious of the plant that radically underbids another from which a satisfactory product has been received. Based upon prices, f.o.b. plant, there exists no royal road in the matters of cost of metal, molding and overhead for castings that are sound.

It is only through the exercise of the greatest ingenuity in molding practice and the use of much unnecessary metal that a sound casting can be produced from an incorrectly designed pattern. Even through the employment of the greatest molding skill available and the use of very heavy risers and heads, patterns are in existence from which no human being could obtain a sound casting, except perhaps at prohibitory cost. Cooperation can remedy this situation.

There exists no ferrous product having any ductility whatsoever that can be machined with anywhere near the speed of the malleable-iron casting. It is the cost of the finished and not of the raw casting that counts. Representatives of 70 different plants are meeting in all-day sessions every month to discuss possibilities of plant improvement and works practice. Other meetings are held incidentally. A large metallurgical engineering force is employed, well equipped chemical and physical laboratories are provided and money is lavishly expended in any direction that gives promise of improving works' practice in any direction. Research is continually in progress. It should be expected that, in the natural course of events, such serious and indefatigable work will result in a still greater improvement of the product.

BALLOON INSTRUMENTS AND METHODS

SOME of the instruments and methods used in piloting the balloon Aero Club of America in the last Gordon-Bennett race are described as follows in *Leslie's Weekly* by Ralph Upson, who piloted the balloon and won third place in the race, traveling a distance of 664 km. (412.59 miles)

Our only important instruments were an ordinary watch; a barograph for indicating and recording the altitude; a "feeler" for maintaining equilibrium; a "navigator" for obtaining horizontal direction and speed: and a "sounder" for investigating currents at other levels. The three last-named of these instruments were entirely original so far as I know, and were a wonderful help in handling the balloon, simply because they made our knowledge of its movements more reliable and exact. The feeler enabled us to get results with a minimum expenditure of ballast and gas, by indicating promptly any forces affecting our equilibrium. This instrument will undoubtedly become standard equipment for airships as well as free balloons. With the navigator we could quickly figure our actual direction and speed whenever we could see a stationary object below and knew our altitude above it.

The most important part of our sounding apparatus consisted of a small rubber balloon filled with hydrogen gas and let up on a string to a point 1000 ft. above the main balloon. Simple though it was in principle, it was made possible for the first time in this race owing to the discovery of a new type of "pilot-balloon," that held gas several hundred per cent better than any we had tried before.

CHROME-MOLYBDENUM-STEEL APPLICATIONS

(*Concluded from page 50*)

take on a given case-depth in 10 per cent less time than chrome-nickel steel; also, there will be a resultant average increase in Shore hardness of from five to seven points.

In spite of the fact that we have not received any complaints with regard to failures of case-hardened parts of chrome-molybdenum steel, and I feel assured we will not in the future, we have seen fit to discontinue this particular grade for this particular purpose. Chrome-nickel steel apparently still holds the first place among commercial steels for case-hardening of important parts, but it is the opinion that nickel-molybdenum steel will be a serious contender. At present we have a heat of approximately 100,000 lb. of nickel-molybdenum steel of the following analysis: Carbon 0.130, manganese 0.380, sulphur 0.022, phosphorus 0.020, nickel 1.580 and molybdenum 0.200. This material is being made into gears, knuckle-pins and the like. It is stated that this steel should prove a serious contender with chrome-nickel steel for case-hardening purposes, because of its ability, in the hot-rolled condition, to harden in oil after carbonizing. This statement may not be wholly clear to some, but it is a fact that a piece of hot-rolled steel of a given composition after carbonizing will not harden in oil to the degree that a piece of the same composition will if first subjected to forging.

The steering-knuckle pin has been one of our problems. This pin is made from ⅞-in. round hot-rolled stock and from alloy steel. It is case-hardened and a Shore hardness of 70 is required after final grinding. It always has been necessary to water-harden this piece, irrespective of the type of steel we use and, as a result, there is always a certain percentage of loss due to straightening. To illustrate, in one lot of 1949 nickel-molybdenum pins carbonized and hardened in oil, only 10 fell below 75 above hardness, none was lost in straightening or because of softness after final grinding. This we think is a remarkable record in view of the fact that chrome-nickel, chrome-vanadium, chrome-molybdenum and 3½-per cent nickel steels have all been tried without success.

To summarize this portion of the subject briefly, our observations lead us to believe that, for carbonizing purposes, chrome-molybdenum steels should prove entirely satisfactory for parts in which hardness alone is the chief factor, but should be considered carefully before being used for important parts in which combined toughness and hardness are requisite, such as gears, steering-knuckle pins and the like.

The results thus far obtained with nickel-molybdenum steel are very satisfactory in every way when compared with chrome-nickel steel, with the added advantage of the greater hardness that can be obtained from an alloy-steel of the former type.

There are many more details that could be added to the above, but I feel that they might serve to confuse rather than enlighten those desiring a frank statemert of conditions pertaining to two important grades of chrome-molybdenum steel. In connection with the oil-hardening and spring steels we are at present in the midst of exhaustive investigation, but are not yet in a position to express an opinion.

THE ATOMS

AT present we have, I think, to accept it as a fact that the atoms consist of a positively charged nucleus of minute size, surrounded at a fairly respectful distance by the number of electrons requisite to maintain the structure electrically neutral. The nucleus contains all but about 1/2000 part of the mass of atom, and its electric charge is numerically equal to that of the negative electron multiplied by what is called the atomic number of the atom, the atomic number being the number that is obtained when the chemical elements are enumerated in the order of the atomic weights; thus hydrogen—1, helium—2, lithium—3, and so on. Consequently the number of external electrons in the atom is also equal to the atomic number.

The diameters of the nuclei of the atoms are comparable with 0.000000000001 cm. and the problem of finding what lies within the interior of such a structure seems at first sight almost hopeless. It is to this problem that Rutherford has addressed himself by the direct method of bombarding the nuclei of the different atoms with the equally minute high-velocity helium nuclei, alpha-particles, given off by any radioactive substances, and examining the tracks of any other particles that may be generated as a result of the impact. A careful and critical examination of the results shows that hydrogen nuclei are thus expelled from the nuclei of a number of atoms such as nitrogen and phosphorus. On the other hand, oxygen and carbon do not eject hydrogen under these circumstances, although there is ample and uncontrovertable evidence in the case of oxygen and nitrogen of the expulsion of other sub-nuclei, the precise nature of whose structure is a matter for further inquiry.

The artificial transmutation of the chemical elements is thus an established fact. The natural transmutation has, of course, been familiar for some years to students of radio-activity. The philosopher's stone, one of the alleged chimeras of the mediæval alchemists, is thus within our reach. But this is only part of the story. It appears that in some cases the kinetic energy of the ejected fragments is greater than that of the bombarding particles. This means that these bombardments are able to release the energy that is stored in the nuclei of atoms. Now, we know from the amount of heat liberated in radioactive disintegration that the amount of energy stored in the nuclei is of a higher order of magnitude altogether, some millions of times greater, in fact, than that generated by any chemical reaction such as the combustion of coal. In this comparison, of course, it is the amount of energy per unit mass of reacting or disintegrating matter that is under consideration. The amounts of energy that have thus far been released by artificial disintegration of the nuclei are in themselves small, but they are enormous in comparison with the minute amounts of matter affected. If these effects can be sufficiently intensified there appear to be two possibilities. Either they will prove uncontrollable, which would presumably spell the end of all things, or they will not. If they can be both intensified and controlled, then we shall have at our disposal an almost illimitable supply of power that will entirely transcend anything hitherto known. It is too early yet to say whether the necessary conditions are capable of being realized in practice.—Prof. O. W. Richardson, president, Mathematics and Physics Section of the British Association.

Bomb Dropping

A SUBMARINE is necessarily a very small target seen from the air, but not so cruisers and battleships and the resulting risk to the latter is so much the greater. To many persons, as an examination of the patent records makes abundantly clear, the problem of hitting a target is regarded as solved if the airman can manage to release his bomb at the moment he ascertains himself to be precisely over the target. In reality this is about the best way of making it absolutely certain that the bomb will miss its mark.

If an airman flies his machine on a steady course and at some given moment releases a bomb, he will notice that it remains vertically below him until such time as it strikes the sea, taking about ½ min. to fall from 10,000 ft. In other words, it will appear to him to fall in a vertical straight line. The effect of air resistance is small and not readily noticeable to the eye. But it must be recollected that this line, though vertical is not stationary but is moving with the airplane; hence a surface object that is in this vertical line at the moment of release will not be in the vertical from the aircraft at the later instant when the bomb reaches the sea level. In fact the distance apart of these two lines will be given by the product of the time of fall of the bomb by the speed of the airplane over the sea. With a time of fall of 30 sec. and a speed of 100 m.p.h. this distance is over ¾ miles; evidently therefore if the bomb is to hit the target it needs to be released 30 sec. before the aircraft reaches the point vertically over the target; and the aircraft must be pointed in precisely the right direction, or else the bomb will fall to the right or left of the target.

There are, then, two main errors to be guarded against; one due to releasing the bomb either too early or too late, and so either undershooting or overshooting the target, and the other due to the aircraft not pointing in precisely the correct direction, so that the bomb misses the target by falling to one side or the other. The former error can be guarded against by using a sighting device to indicate the precise moment for release, and the latter by the pilot paying close attention to the steering of the craft.

Design of Sights

An observer on the ground would not, perhaps, notice that the path of the bomb was one that must appear vertical as seen from the aircraft. Observing the motion of the bomb against a stationary background, he would describe its path as curved, in fact as parabolic. It is this parabolic path that to a ground observer, seems to make for complication in judging the correct moment for release; but any sighting device will be fixed to the aircraft and carried with it, so that for the devising of a suitable sight the important thing is the trajectory as seen from the aircraft and not as viewed from the ground.

In designing such a sight it is simplest to regard the motion of the bomb relative to the earth as made up of two components; the motion of the bomb relative to the aircraft, which is gradually increasing velocity in a vertical straight line, and the motion of the aircraft relative to the ground. The addition of these two by the usual triangle of velocities gives the motion of the bomb relative to the target, and if when the closing side of the triangle points at the target the bomb is released it will hit the target, provided that the pilot is steering a correct course.

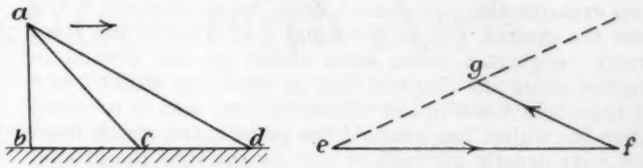


Diagram Showing the Relation between the Path of a Bombing Airplane, the Wind and Objects on the Ground

Estimation of Ground Speed

The average speed of the bomb relative to the aircraft is easily computed since it is always equal to four times the square root of the height measured in feet. Thus for a height of fall of 10,000 ft. the mean vertical velocity of the bomb is 400 ft. per sec. The velocity of the aircraft relative to the earth is more difficult to estimate. It is made up of two parts; its velocity relative to the air and the velocity of the air relative to the earth, which is, of course, the wind. If an aircraft is flying through the air at 100 m.p.h. and the wind has a velocity of, say 40 m.p.h. in the opposite direction, the speed of the aircraft over the ground which is commonly called the ground speed will be but 60 m.p.h. whereas if the wind were behind the airplane its ground speed would be 140 m.p.h. In the earlier days of bombing it was usual to drop bombs up-wind, occasionally to drop them down-wind, and never, intentionally, to attack across the wind. The speed through the air is given by the air-speed indicator, corrected so far as is necessary for the loss of air density with the altitude, but there is no dial on the aircraft that can give the velocity of the wind. On the other hand, it is possible by using a stop-watch to determine the ground speed by watching the rate of slipping away of the ground immediately below. For instance, it is easy to note the time taken for some ground object to pass from a point where it is 45 deg. ahead of the vertical to a point when it is directly below; in this time the aircraft must have moved a horizontal distance equal to its height, and, by dividing this by the time taken, a measure of the ground speed is at once obtained. Then with a knowledge of the ground speed and the mean vertical velocity of the bomb, the triangle of velocities can be set up in a linkwork, and an elementary form of bomb-sight provided. Such a sight would have its fore-sight moved along a horizontal scale of ground speeds and its back-sight along a vertical scale of altitudes, the distance being marked off to the square root of the altitude.

Simplified Methods

A most ingenious simplification of this procedure was introduced by Bourdillon in what was known as the C.F.S. sight. In this the distance timed over was not equal to the altitude, but was proportional to its square root. The arrangement can be shown algebraically to lead to two very useful results; one that no calculations need be made and the other that the back-sight can be left fixed and only the fore-sight need be moved. An almost contemporaneous invention was the equal-distance sight associated in England with the name of Scarff. In this a reversing stop-watch was used; at the first pressure

of the knob the watch hand started, at the second it reversed its direction, and at the third it sprang back to zero.

The diagram at the left of the accompanying illustration explains the procedure. Let *a* be an airplane flying over the ground, and let *b c* equal *c d*. Then if the stop-watch be started when some object on the ground is sighted along the line *a d* that is when the object bears at the angle *b a d* ahead of the vertical, and is reversed when the object has reached the point *c*, the watch hand will have exactly got back to zero by the time the ground object has reached *b*, the point vertically below the airplane. Now to hit the target the bomb must be dropped the same number of seconds before the target reaches *b* as it takes for the bomb to fall from *a* to *b*. Hence if a series of marks be put on the watch dial at times equal to the time of fall at various heights, the moment at which to release the bomb is when the reversed watch hand has come opposite the mark corresponding to the altitude of flight. Thus the moment to release is indicated by watching the watch, and not, as in the C.F.S. sight, by watching the target. This sight is of special advantage for use at sea, as it can be set by observations of the target itself even if, as frequently is the case, the latter is a ship under way. By sighting on the moving ship instead of on a fixed object on the earth the necessary allowance is automatically made for the ship's own motion.

Drift Bomb-Sights

Difficulty arises, however, in making careful observations in the excitement of an attack, and if it be desired to avoid altogether the use of a stop-watch, an alternative procedure is offered by the use of the drift bomb-sights developed by Wimperis. If an airplane be deliberately flown across the wind, the direction of the apparent drift of earth objects will be inclined to the fore-and-aft of the craft. This angle is called the angle of drift. Its amount is clearly proportional to the wind velocity; in fact, its tangent is given by the wind velocity divided by the air speed. A sight can therefore be devised in which, by setting a drift bar parallel to the earth drift when flying across wind, the foresights for up and down-wind bombing are automatically set to their true position and the actual velocity of the wind can be read off a scale. Equally, of course, if the velocity of the wind be given, it is possible to set the sight without any drift observations at all.

To bomb precisely up or down wind is, however, not so simple as it sounds. If, for example, an attempt at up-wind bombing be made, but the course chosen is somewhat inclined to the wind, the target will be missed. Thus if in the drawing at the right *e f* be the air speed and *f g* the wind, the airplane and the bomb will follow the line *e g* and not the line *e f*. Hence the bomb will fall much to the left of the target. A later modification of the drift bomb-sight provided for this by enabling the sight to be accurately set even when the flight path is not strictly parallel to the wind. Once this is done there is no need to bother to fly parallel to the wind. The airman is free to fly in any direction relative to the wind he pleases, and nevertheless the sight is always automatically set to the correct sighting position. This is especially of advantage when attacking moving targets, usually moving so as to make it intentionally difficult for the airman, and still more so when operating against disappearing targets like submarines, when there is no time to maneuver for up and down-wind positions, since the attack, if made at all, must be along the very shortest route to the target.

The art of bombing, complicated as it necessarily is by the great complexity and the variability of the factors that enter into it, is nevertheless one in which the use of uptodate sighting instruments affords the same sort of aid as modern gun-sights afford to naval gunnery. But the problem in the air tends to be the more troublesome to deal with by reason of the irregular, and sometimes violent motion of the relatively small craft in which the instruments are carried.—Engineering Supplement of *The Times* (London).

MECHANICAL INSPECTION IN EXPORT TRADE

AFTER having spent several months in the foreign field as a traveling technical representative for an American motor-car company I feel that there is one matter in connection with automotive manufacturing applying to export products that can be better handled by the engineers, namely, mechanical inspection. In preparing these products for export, the fact that the cars may travel many thousand miles before they reach their destination and in this travel be subjected to conditions entirely foreign to any existing throughout our domestic territories must be given serious consideration. Upon arrival at destination, these cars are set-up by men who perhaps are not thoroughly competent, or lack the necessary equipment to do proper work. Therefore, it behooves American manufacturers to pay special attention to the inspection of goods destined for the export trade. Great care should be taken in the final inspection of engines, electrical apparatus, the clutch, the transmission and the rear axle, as these parts frequently arrive in the foreign field in defective condition.

Many times I have seen new engines torn-down that showed conclusively the abuse and carelessness of some final inspector at the factory, the connecting-rod bearings being loose and it being evident that the engine in its final block-test had been negligently handled and forwarded in bad condition. Electrical appliances arrive out-of-line due to improper mounting, and there are short-circuits that are, in the majority of cases, due to carelessness in wiring. In some instances generators and motors are affected by the change in climatic conditions. Such cases can be remedied only by close study and building to counteract the particular extraordinary conditions.

It is surprising to know that many cars are received with clutches out-of-line or not properly adjusted, involving a great amount of work by the foreign distributers. Transmissions and rear axles are a considerable source of trouble, their bearings being improperly fitted or the meshing of the gears being incorrect.

These conditions have, and if not obviated will continue to have, a marked adverse effect on the sale of American motor cars in foreign countries, as the foreign buyer does not accept excuses readily. Before the war he was more familiar with European cars that are carefully tried-out before shipment, such adjustments as are necessary being made at the factory instead of permitting the car to be forwarded and the chances taken of adjustment at destination under unfavorable conditions. The American motor car has gained great popularity in the foreign field, but to hold this favor, greater care must be exercised in final inspection, as our European competitors are taking advantage of each and every one of our errors.

My remarks do not apply to any one company, but to the automobile export-trade in general. The engineers should institute a far more rigid final inspection than has existed in the past in their respective factories.—Harry F. White.

Total Sensible Heats of Engine Fuels and Their Mixtures with Air

By Robert E. Wilson[1] and Daniel P. Barnard, 4th[2]

Illustrated with Diagram and Charts

THIS article describes certain approximate methods used by the Research Laboratory of Applied Chemistry at the Massachusetts Institute of Technology in determining the total sensible heat content of Socony internal-combustion engine gasoline and kerosene and their mixtures with air at temperatures up to 500 deg. cent. (932 deg. fahr.). The resulting data are presented in such form as to make it readily possible to calculate, with sufficient accuracy for all practical purposes, the resultant temperature of an air-fuel mixture, knowing the temperature of the two constituents before mixing. Combined with the data on the dew-points of various fuel-air mixtures, this information is very valuable in determining the proper conditions for securing a completely vaporized mixture of air and fuel in various types of carbureter and heated manifolds. The results also indicate that the net effect of the compression stroke in an engine is to vaporize, rather than condense, the fuel and hence that the most difficult problem in connection with the vaporization of the fuel is to secure distribution.

A FEATURE that is of paramount importance to the efficient operation of an internal-combustion engine, especially of the high-speed type used in motor cars, is the securing of a uniform mixture of fuel and air in the proper proportions before distribution to the cylinders. The only reasonably practicable way of accomplishing this seems to be in having the fuel nearly, or preferably, completely vaporized. To vaporize present commercial gasoline or any less volatile fuels completely, it is necessary to add some heat from external sources.[3] It is possible to secure satisfactory vaporization by any one or more of three methods, which may be classed as follows:

(1) Atomization of cold fuel into heated air
(2) Atomization of cold fuel into cold air followed by heating the resulting mixture in the manifold. The "hot-spot" aids vaporization partly by heating the mixture as a whole, but to a greater extent by throwing the uncondensed drops onto the heated manifold surface and vaporizing the liquid directly
(3) Injection of the fuel as a superheated vapor into cold air

The first two methods are frequently combined in the use of the hot-spot in conjunction with a preheater. These methods suffer from a fundamental defect in that it has been found necessary to superheat the air or mixture considerably above its theoretical dew-point in order to vaporize the fuel completely in the short time available. This results in a decreased volumetric efficiency coupled with an increased tendency toward knocking. The last method, however, starts from the other side of equilibrium and therefore is theoretically the best means of securing the proper mixture, as it is necessary to heat the vaporized fuel only to such a temperature that the resulting mixture will be approximately at the dew-point. Indeed, experimental results in this laboratory and elsewhere have shown that the mixture prepared by this method may be as much as 30 to 35 per cent condensed before the distribution is seriously affected, even in a poorly designed manifold, because the extremely small particles formed by the rapid condensation of the superheated vapor do not tend to separate readily from the air-stream. The particles then produced are, at least for the first few moments after condensation begins, far smaller than those obtained by the best methods of atomizing a liquid.

The practical application of the third method requires fairly accurate data on two subjects; (*a*) the dew-points of various fuel-air mixtures; and (*b*) the specific heats, or rather, the total sensible heats, of the fuels at high temperatures. The data on dew-points have been covered in the article previously mentioned. It is the purpose of this article, therefore, to cover only the subject of specific and total sensible heats.

A survey of the available literature failed to yield any data on specific heats of paraffin hydrocarbons at the high temperatures required. Practically the only work done along these lines indicated that up to 100 deg. cent. (212 deg. fahr.) the specific heat, averaged for a large number of petroleum distillates in the liquid state, could be represented with a fair degree of accuracy by the equation modified from Bushong and Knight[4]

$$C_p = 0.5000 + 0.0008\,t$$

where

C_p = specific heat at constant pressure
t = temperature in degrees centigrade

Other data[5] indicate that the specific heat at room temperature of light petroleum distillates is very close to 0.5. Such data as are available indicate, as do the vapor-pressure curves, that the specific heats of the liquid and the vapor are substantially equal over the temperature range involved.

While the existing data on the heats of vaporization of hydrocarbons are variable, as is shown in Table 1, it is nevertheless possible by combining these data with Trouton's rule that the heat in calories required to vaporize one molecular weight in grams of a non-associated liquid is equal to 20.5 times the temperature of the boiling point in degrees centigrade absolute, which is known to hold quite well for hydrocarbons, to derive fairly satisfactory values for gasoline and kerosene.

For this work, the best values for the heats of vaporization were chosen as 60 calories per gram for Socony kerosene, the average boiling point of which corresponds to dodecane, and 70 calories per gram for Socony gasoline, the average boiling point of which corresponds to octane. These figures represent a sufficiently good approximation for present purposes.

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[3] A discussion of this subject will be found in a paper by the authors entitled Condensation Temperatures of Gasoline and Kerosene-Air Mixtures, which was published in The Journal, November, 1921, p. 313.

[4] See *Journal of Industrial and Engineering Chemistry*, vol. 12, p. 1197.

[5] See *American Chemical Journal*, vol. 28, p. 66; *Journal of Industrial and Engineering Chemistry*, vol. 6, p. 727, and *Zeitschrift für Angewandte Chemie*, vol. 12, p. 621.

TABLE 1—HEATS OF VAPORIZATION OF HYDROCARBONS IN CALORIES PER GRAM

Hexane C_6H_{14}	Heptane C_7H_{16}	Octane C_8H_{18}	Nonane C_9H_{20}	Decane $C_{10}H_{22}$	Undecane $C_{11}H_{24}$	Dodecane $C_{12}H_{26}$	Source
79.4	74.1	71.1		60.8			Maybery & Goldstein
		63.54	63.1	62.0		60.0	Syniewski
	74.0					60.0	Ricardo
81.6	74.5	71.5	67.5	64.5	61.4	59.0	Trouton's Rule
		65.3				60.5	Wilson and Barnard*

*From slopes of vapor-pressure curves in paper entitled Condensation Temperatures of Gasoline and Kerosene-Air Mixtures.

On account of the paucity of data at the higher temperatures, our laboratory undertook to make some approximate experimental determinations of total sensible heats of two typical internal-combustion engine fuels up to about 500 deg. cent. (932 deg. fahr.). The experimental method used in securing these data was

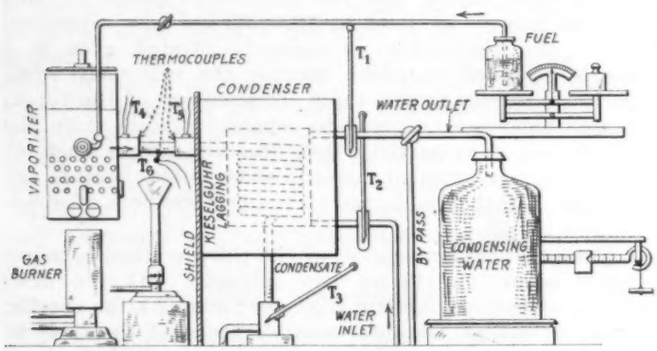

FIG. 1—APPARATUS EMPLOYED IN DETERMINING THE SENSIBLE HEATS OF VAPORIZED FUEL

probably not accurate to closer than 3 or 4 per cent, but is sufficiently near to the truth for all practical work, especially in view of the rather indefinite composition of the materials investigated. The publication of the data appears worth while in view of the practical importance of the subject and the complete lack of any similar data in the literature.

EXPERIMENTAL WORK

The experimental work was confined to two fuels, Socony kerosene and Socony gasoline. The gravity of the kerosene was 45 deg. Baumé, corresponding to a specific gravity of 0.800; and that of the gasoline was 60 deg. Baumé, corresponding to a specific gravity of 0.743.

The total heats of these fuels were determined at various temperatures in the apparatus shown in Fig. 1. The distillate from the vaporizer, which was heated by a gas blast burner, was continuously condensed in a water-cooled steel coil. The condenser was tightly lagged with about 2 in. of kieselguhr and the temperatures of the inflowing and outflowing cooling water were read from the thermometers T_1 and T_2. The cooling water was caught and weighed for each run. The weight of the cooling water multiplied by the difference in the temperatures T_1 and T_2 equals the heat given up by the fuel in cooling to the discharge temperature, T_3. The thermometers T_1 and T_2 were checked against each other, and showed no deviation over the range of temperatures involved. The vapor temperatures were measured by thermocouples placed at T_4 and T_5, and the air temperature around the vapor pipe, indicated by the thermocouple T_6, was kept slightly above that of the vapor to prevent more

TABLE 2—RESULTS OBTAINED AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Specific Heat Data

Fuel	Run	Length of Run, min.	Heat Loss Correction	Determined	Corrected	$Q - r$	Temperature deg. cent.	Temperature deg. fahr.	r
Kerosene	1	12	24	336	360	300	460	860.0	60
Kerosene	2	12	24	317	341	281	461	861.8	60
Kerosene	3	12	24	317	341	281	459	858.2	60
Kerosene	4	12	24	321	345	285	461	861.8	60
Kerosene	5	10	20	265	285	225	375	707.0	60
Kerosene	6	10	20	270	290	230	375	707.0	60
Kerosene	7	10	20	262	282	222	365	687.0	60
Kerosene	8	8	16	239	255	195	327	620.6	60
Kerosene	9	8	16	233	249	189	318	604.4	60
Kerosene	10	8	16	236	252	192	314	597.2	60
Gasoline	11	14	28	308	336	266	446	834.8	70
Gasoline	12	14	28	300	328	258	434	813.2	70
Gasoline	13	14	28	265	293	223	376	708.8	70
Gasoline	14	12	24	242	266	196	338	640.4	70
Gasoline	15	12	24	227	251	181	338	640.4	70
Gasoline	16	12	24	235	259	189	340	644.0	70
Gasoline	17	12	24	230	254	184	328	622.4	70
Gasoline	18	8	16	202	218	148	290	554.0	70
Gasoline	19	8	16	200	216	146	289	552.2	70
Kerosene	20	8	16	219	235	175	308	586.4	60
Kerosene	21	8	16	230	246	186	308	586.4	60
Kerosene	22	8	16	220	236	176	300	572.0	60
Water	23	20	40	756	797†	...	434	813.2	..
Water	24	20	40	757	798†	...	440	824.0	..

†From Marks and Davis Steam Tables h at 434 deg. cent. (813.2 deg. fahr.) = 1433 ÷ 1.8 = 797 calories. The difference between the observed value and that given above = 798 — 757 = 41 calories loss by radiation, etc., per gram of fuel in 20 min.

than minor heat losses. A variation of 75 to 100 deg. cent. (167 to 212 deg. fahr.) in the air temperature produced no appreciable change in the vapor temperatures.

In making the determinations, the apparatus was allowed to run until substantially constant temperatures had been maintained at all points for at least 10 min. The time was then noted and the condensing water caught while 500 grams of fuel passed through the generator, readings being taken frequently to check the temperatures. All runs were discarded in which the water temperatures varied over 1.0 deg. cent. (1.8 deg. fahr.) In most cases the variation was less than 0.5 deg. cent. (0.9 deg. fahr.) Several check runs were made at each temperature, the results of which are indicated in Fig. 2.

Since the condenser was admittedly not adiabatic, it seemed desirable to determine approximate figures for the heat losses and other correction factors by passing water through the generator and condenser, and comparing the total heat of the steam as thus determined with the values given in Marks and Davis Steam Tables. The results were found to be 41 calories per gram too low for 500 grams of water vaporized over a period of 20 min. The heat losses were therefore assumed to be 2 calories per gram per min., and the results of the other determinations were subjected to this correction which remains constant for all determinations, as the *same* weight of fuel was passed through in each case.

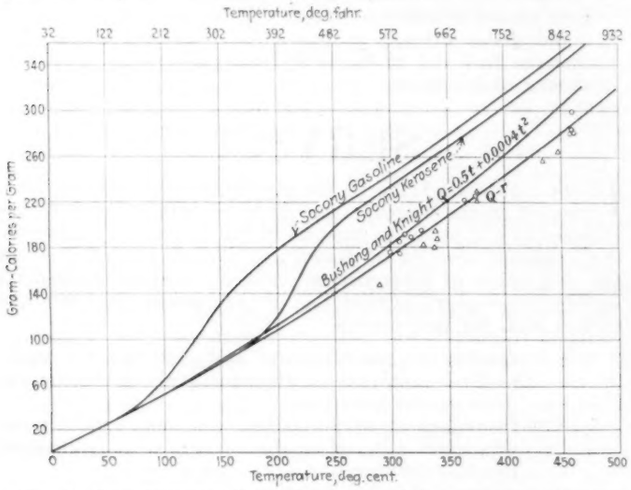
Temperature, deg. fahr.
32 122 212 302 392 482 572 662 752 842 932
340 300 260 220 180 140 100 60 20
Gram-Calories per Gram
Socony Gasoline
Socony Kerosene
Bushong and Knight $Q=0.5t+0.0004t^2$
$Q=t$
0 50 100 150 200 250 300 350 400 450 500
Temperature, deg. cent.

FIG. 2—THE SENSIBLE HEAT CURVES OF KEROSENE AND GASOLINE

RESULTS

The experimental results as obtained by the foregoing procedure are recorded in Table 2. The total sensible heats have all been corrected to 0 deg. cent. (32 deg. fahr.)

It is very desirable to tie in these high-temperature data with the values given in the literature for the specific heats of these hydrocarbons in the liquid state. This cannot be done directly, but by subtracting the value of r, the heat of vaporization of the fuel in question, from the observed figures for the total sensible heat at high temperatures, values can be obtained that should lie on a smooth curve with the data for the sensible heat of the liquids at temperatures below the boiling point. This method of treatment of the results is, of course, rigidly applicable only in cases where the heat of vaporization is substantially constant over the temperature range in question, and hence the specific heats of the liquid and the vapor are equal at a given temperature. That this is substantially true for the paraffin hydrocarbons in question is indicated both by data in the literature and by the fact, discussed in the article on condensation temperatures, that the vapor-pressure data obtained for these fuels gave straight lines when log p was plotted against $1/T$.

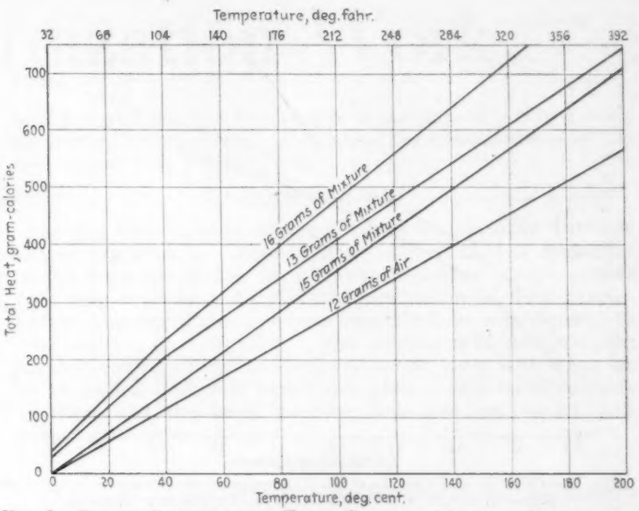
Temperature, deg. fahr.
32 68 104 140 176 212 248 284 320 356 392
700 600 500 400 300 200 100 0
Total Heat, gram-calories
16 Grams of Mixture
13 Grams of Mixture
15 Grams of Mixture
12 Grams of Air
0 20 40 60 80 100 120 140 160 180 200
Temperature, deg. cent.

FIG. 3—CURVES SHOWING THE TOTAL SENSIBLE HEATS OF KEROSENE-AIR MIXTURES

The values thus obtained are presented in column seven of Table 2, and graphically in Fig. 2. For comparative purposes a line is drawn to represent the extrapolation of the recent data of Bushong and Knight[8] which was obtained from specific-heat measurements on light petroleum distillate, liquid only, at temperatures up to 100 deg. cent. (212 deg. fahr.). It will be noted that the agreement is not bad considering the unjustifiable extrapolation of Bushong and Knight's equation

$$C_p = 0.5000 + 0.0008\ t$$

where

C_p = specific heat at constant pressure
t = temperature in degrees centigrade

The best representative line for the points determined in this Laboratory lies below the curve of Bushong and Knight and accords best with the equation

$$C_p = 0.5000 + 0.0006\ t$$

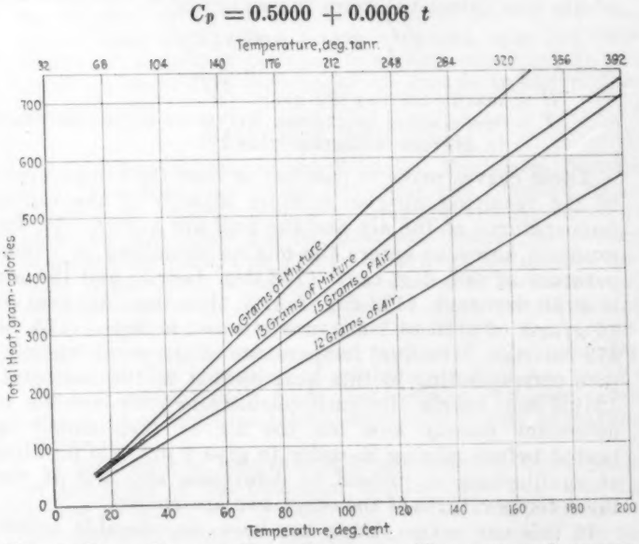
Temperature, deg. fahr.
32 68 104 140 176 212 248 284 320 356 392
700 600 500 400 300 200 100 0
Total Heat, gram-calories
16 Grams of Mixture
13 Grams of Mixture
15 Grams of Air
12 Grams of Air
0 20 40 60 80 100 120 140 160 180 200
Temperature, deg. cent.

FIG. 4—TOTAL SENSIBLE HEAT CURVES FOR MIXTURES OF GASOLINE AND AIR

[8] See *Journal of Industrial and Engineering Chemistry*, vol. 12, p. 1197.

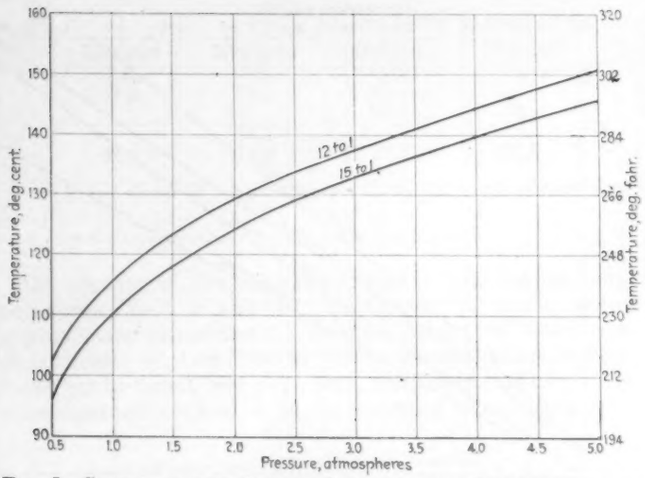

FIG. 5—CURVES OF THE INITIAL CONDENSATION TEMPERATURES OF KEROSENE-AIR MIXTURES HAVING DIFFERENT RATIOS

It will be noted that values obtained for gasoline lie, on the average, about 5 calories below the $Q - r$ points for kerosene. This discrepancy, which is in the opposite direction from what might be expected, is possibly due to the assumption of too large a value for the heat of vaporization for the gasoline. The value obtained from the slope of the vapor-pressure curve of the identical fuel was, as indicated in Table 2, 65.3 calories per gram, but a value of 70 was assumed in determining $Q - r$ because it accorded better with other data in the literature.

Assuming, however, that the line $Q - r$ is correct as drawn for both fuels, since the divergence is just about within the limit of error of the method, it is then possible to add to this line the fractional amount of the heat of vaporization that corresponds to the fractional amount of the fuel which is vaporized at any given temperature. This was the method used in obtaining the curved lines shown in Fig. 2, which represent within a probable error of 3 or 4 per cent the values for the total sensible heat of gasoline and of kerosene as a function of temperature at a pressure of one atmosphere.

Figs. 3 and 4 give respectively the sensible heats of kerosene-air and gasoline-air mixtures. The heats are given in gram calories for 13 and 16 grams of mixture, and also for 12 and 15 grams of air. The heat content of air was calculated from the equation[9]

$$29\,H = 6.5\,[T - 273] + 0.0005\,[T^2 - (273)^2]$$

where

H = heat in calories per gram
T = temperature in degrees Kelvin or the temperature in degrees centigrade plus 273

These curves make it possible to read the temperature of the resulting air-fuel mixture directly if the initial temperatures of the air and the fuel are known. If, for example, kerosene enters the mixing chambers at a temperature of 400 deg. cent. (752 deg. fahr.), and the air is at 50 deg. cent. (122 deg. fahr.), then the total heat of 16 grams of a 15 to 1 mixture is equal to 304 + 175, or 479 calories. The final temperature of the resulting mixture corresponding to this heat content is 104 deg. cent. (219.2 deg. fahr.) By such calculations it is possible to determine exactly how hot the air or fuel should be heated before mixing in order to give a dry gas mixture at equilibrium, or indeed to determine any one of the three temperatures if the other two are known.

In this connection, there has been considerable speculation as to what happens with regard to the condensation or evaporation of the fuel during the compression cycle of an Otto cycle engine. The increase in the pressure taken by itself would, of course, tend to cause condensation, but the heat liberated during the compression would raise the temperature of the mixture and tend to evaporate any uncondensed fuel. Without accurate data as to the change of the vapor pressure with the temperature and the sensible heat of a given fuel, it was impossible to give a definite answer to these questions, but from data presented in this and in our previous paper definite conclusions can be drawn as follows:

> Making the calculations on a 5 to 1 compression ratio for Socony kerosene and assuming that the value of the exponent in the equation pv^k = a constant for the compression is 1.2, which makes a maximum allowance for cooling during compression, it can be shown readily that the tendency of the compression as a whole is to vaporize rather than condense the fuel, and indeed, that theoretically it would be possible to vaporize by compression a mixture of kerosene and air which was initially 75 per cent condensed. Actually, of course, the time would probably be insufficient to vaporize this amount of material, but it seems certain that if the mixture is near enough to complete vaporization as to give proper distribution, there will be very few, if any, liquid drops present at the moment of ignition, and that the fuel will, under no circumstances, condense out during compression.

[9] See General Principles of Chemistry by Noyes and Sherrill.

SERVICE

IF the maximum value to the user with the minimum service-cost to the manufacturer is to be attained, the future changes in our products must be in the direction of eliminating needless varieties in design and toward the selection of the best types of construction. The elimination of needless variety is necessary to reduction of both production costs and service costs for two reasons

(1) Quality of workmanship and material are more easily maintained as the variations in mechanical practice are decreased
(2) Incompetence of the service workman can be more effectively reduced as the variations in mechanical practice decrease

It necessarily follows that future changes in automotive products should not only lead toward the elimination of needless variety, but the maintenance of the needed variety and the correct use of these variances with respect to more intelligent marketing policies. The success of a company is primarily dependent upon the adequacy of its sales and service. There should be a more equitable working arrangement between these two most important phases of the industry.

If the retail service-station has been inefficient, it is we who are to blame. There is a total of 45,135 automobile repair shops in the United States. It stands to reason that the individuals operating these repair shops do not have the same opportunities to develop proper methods of servicing our products as do we. We must begin to take greater advantage of our facilities and give our dealers the advantage of our best experience. Efficiency is responsibility met. We have not met our service responsibility until we place repair parts within immediate reach of our car owners, even in the most remote sections of this country. All other things being equal, the usefulness of any automotive product is inversely proportional to the time lost on account of repairs.

The automotive industry leads all others in the fields of scientific research, invention, engineering, processing and manufacturing. The efficiencies and economies exercised in our modern plants are the standards of the world, but the injection of similar standards and efficiencies into our marketing and servicing methods is yet to be accomplished.—Norval A. Hawkins.

Current Standardization Work

ALTHOUGH the definite recommendations of the Divisions of the Standards Committee were published in the December issue of THE JOURNAL, many other subjects are being actively considered by Subdivisions, as is indicated hereinafter, with a view to submitting reports at the Division meetings to be held during the coming year. As soon as the Standards Committee personnel for 1922 is appointed by the Council, tentative Division meeting schedules will be determined upon and announced so that committee members can plan to take care of business as well as standardization matters on any trips necessitated in attending the Division meetings.

BASES, SOCKETS AND CONNECTORS

The Lighting Division is considering a proposal that the tolerances for the diameters of the standard bases and sockets for head-lamp bulbs should be reduced, as it is stated that they are wider than necessary and permit sufficient play to cause considerable variation in the position of the filament and consequently the illumination characteristics of the lamps. It is felt that although narrower limits are not essential, they would improve the specifications and not introduce undue restriction on manufacturers of the parts.

BRAKE-LINING

A meeting of the Subdivision on Brake-Lining was held in October in New York City, F. C. Stanley, of the Raybestos Co., G. W. Skirm, of the United & Globe Rubber Co., W. D. Pardoe, of the Thermoid Rubber Co., C. Bockius, of the Manhattan Rubber Mfg. Co., R. H. Soulis, of the Multibestos Co., and C. Carsson, formerly with Johns-Manville, Inc., being present. All of the companies represented at the meeting having had in operation brake-lining testing machines similar to the one being used at the Bureau of Standards, there was a general discussion of the machine. It was stated that some trouble had been experienced in getting the apparatus to function satisfactorily, apparently on account of minor manufacturing defects and the fact that there had not been sufficient time to get the machines adjusted and running properly. A discussion of the method of testing seemed to indicate general approval of the use of this machine when run at 600 r.p.m. without water-cooling with a load of 6 hp.

It is felt that some supplementary test must be developed which will approximate the temperature conditions and unit pressure encountered on a passenger car in the ordinary intermittent service application of brakes. No definite outline of this test was reached at the meeting.

It was agreed that a quantity of folded and stitched lining and a like quantity of woven lining, none of the material being confined to that made by any one company, would be purchased and 6 ft. of each type of lining tested by the companies represented with the machines operating under similar conditions. The results, including those of the Bureau of Standards, will be compared to find out what degree of uniformity shall have been obtained, this being the next step toward developing a standard specification.

BREAKER CONTACTS

At the last meeting of the Electrical Equipment Division it was decided to consider the standardization of the hexagon stock used in making timer-distributor contact-breakers. It was stated that there is considerable variation in the size of stock used for mounting the breaker-points, necessitating a number of sizes of wrench for adjusting this part on the several types of ignition apparatus.

It was suggested that ¼-in. hexagon stock be considered for adoption as standard, and that if this is not feasible, the standard should embody a range of two or possibly three sizes such as 3/16, ¼ and 5/16-in. It was argued also that the proposed standard should embody the height of the hexagon and the size and length of the thread. Information on present practice is to be obtained for consideration at the next meeting of the Division.

DOOR-HANDLES

At the last meeting of the Passenger-Car Body Division it was reported that investigation showed that a center-to-center distance of 1½ in. between escutcheon-plate screws was very common. As the standardization of door-handle-square bearing diameters was suggested, it was decided to continue the investigation. The subject was assigned for further consideration to G. E. Goddard, who will make an investigation covering escutcheon-plates, door-handle-square bearings and the bevel on door lock-bars and escutcheon-plate screw sizes.

DOOR-HINGES

Discussion of this subject indicated that it may be possible to standardize some features of exposed hinges, the following dimensions being submitted as desirable practice.

Type	Plate Width, in.	Thickness, in.	Screws No.	Size
Malleable	1¾	3/16	4	No. 10
or				
Forged	2	1/4	4	No. 12
Pressed	2	1/8	4	No. 12

Clearance between plates shall be 1/16 in. at the exposed end, tapering to ⅛ in. at the concealed end when hinges are closed.

As it was advocated that hinge-pin diameters, hinge offsets and possibly hinge projections be standardized, it was decided to give this subject further consideration. E. G. Simpson was appointed a Subdivision of one to secure the necessary data and prepare a tentative recommendation.

ELECTRICAL EQUIPMENT NOMENCLATURE

The use of the term "Timer-Distributor" was thoroughly discussed at the Standards Committee Meeting held on May 24, 1921, and several negative votes were cast against the adoption of the term by members of the Society in the July 1921 Society Letter Ballot on the adoption of standards. The comments submitted were discussed at the Oct. 17 meeting of the Electrical Equipment Division and the opinion was expressed that "Timer-Distributor" is the most suitable term and should be retained. Chairman Libby stated that he had noticed that the term is used in the majority of cases in technical references and in about 80 per cent of the patent investigations that he has conducted, and that these sources indicate that the term is of long standing. It was therefore decided to recommend no change in the present nomenclature.

GENERATOR MOUNTINGS

At the last meeting of the Electrical Equipment Division T. L. Lee, chairman of the Generator and Starting Motor Subdivision, reported that, after studying the suggestion to omit the dimensions for the pilot specified in the present Standard for Generator Flange Mountings, he did not consider it advisable to do so. The discussion indicated that although one large manufacturer of electrical equipment, which suggested omitting the pilot dimensions, does not use pilots on its equipment, a large number of other manufacturers do. The advantage of retaining the pilot was pointed out and the statement made that when a customer orders equipment on which no pilot is desired, it is easy to machine off the pilot.

A suggestion in reference to lengthening the threaded-end of the shaft of the Generator Bracket Moulding was discussed at length and the decision reached that a change is not desirable owing to the limited space provided for the couplings, particularly in present engine designs.

The Subdivision was assigned the work of standardizing a strap mounting for generators. This had been suggested by an automobile builder, it being stated that a standard should specify a generator barrel-diameter of a sufficient distance along the barrel to give a stable mounting, with tolerances of possibly plus or minus 0.002 in. applying to the diameter. It was also said that a standard should establish certain limits for the concentricity between the finished part of the barrel and the armature shaft.

Lubricating Oils

The Lubricants Division is formulating definite specifications for lubricating oils for use in internal-combustion engines with the exception of aircraft and Diesel engines. The specifications tentatively outlined follow in general the specifications of the American Society for Testing Materials and those given in the Bureau of Mines' Bulletin No. 5 in accordance with recommendations of the Interdepartmental Committee on Standardization of Petroleum Specifications.

At a recent meeting of the Division it was stated that compounded or blended oils are being used by a number of engine builders, due partly to their successful use in Europe, and that acidless tallow and castorated oils are used to some extent. Discussion as to what kinds of oils should be taken into consideration in formulating specifications led to the decision to confine the recommendations to straight mineral oils. It was thought that if specifications for blended oils are desirable, they can be developed after the Division shall have had an opportunity to obtain more information as to their use.

Magnet Wire

At the last meeting of the Electrical Equipment Division it was decided to take up the standardization of magnet wire for automotive apparatus, including both fabric and enamel insulation types. A. D. T. Libby, chairman of the Division, has appointed a Subdivision to prepare a tentative specification. It was the consensus of opinion that the specifications for the copper wire should conform with Specification No. B3-15 of the American Society for Testing Materials and that all wire sizes should be drawn to the American wire gage.

Metric Roller Bearings

At the meeting of the Ball and Roller Bearings Division held on Oct. 11, 1921, it was voted to request the Subdivision on Roller Bearings to continue consideration of the following revisions of the present S.A.E. Standards for Roller Bearings, proposed by the Subdivision on Nov. 20, 1918, as it was felt by those present that the demand for standard metric roller-bearing sizes that are interchangeable with the wide or double-row type ball bearings is becoming greater. It was stated at the meeting that the present dimensions of the standard metric roller-bearings are generally considered very satisfactory, although possibly a few changes in tolerances, overall widths and corner radii should be made. All members present were of the opinion that these standards should be put into the best form possible.

Bearing Numbers—Bearings of the light series shall be designated by prefixing the letter *L*, the numbers ranging from L04 to L22 consecutively, and bearings of the medium series by prefixing the letter *M*, the numbers ranging from M04 to M22 consecutively

Inside and Outside Diameters—The inside and outside diameters shall be given in integral millimeters and shall correspond to the inside and outside diameters for the same sizes of the annular ball bearing of the light and medium series, pages C26 and C28, S.A.E. Handbook

Widths—The widths shall be given in inches and shall be in accord with the widths of the annular ball bearings of the wide type, page C31, S.A.E. Handbook

New Sizes—The medium series shall be extended to specify dimensions for bearings Nos. M21 and M22; the inside diameter for bearing No. M21 to be 105 mm., the outside diameter 225 mm., and the width 3 7/16 in.; and the inside diameter for bearing No. M22 to be 110 mm., the outside diameter 240 mm. and the width 3⅝ in.

Chamfers—The chamfer or radius on the inner and outer races of bearings of the light and medium series with inside diameters from 20 to 25 mm. shall be 1 to 1½ mm.; for inside diameters from 30 to 50 mm., the chamfer shall be from 2 to 4 mm.; and for inside diameters from 55 to 110 mm., the chamfers shall be from 3 to 5 mm. The headings of the columns in the tables giving the chamfers shall read "Radius or Chamfer C" and the limits shall be shown as maximum and minimum

Clearances—The maximum clearances required for the bearing cage, when used, shall be given for each size of bearing. These clearances shall not be considered as standard, but as general information only

Eccentricity Tolerances — Further consideration shall be given to the question of whether the eccentricity tolerances given in the present S.A.E. Standards refer to the error in running truth actually measured or to the true eccentricity of the center of the inner and outer races

Diameter Tolerances — Further consideration shall be given to the tolerances for the diameter, as these depend upon the type of bearing and its application

Motor-Truck Cabs

It has been requested that the Truck Division standardize the mounting dimensions for motor-truck cabs so as to permit interchangeability. This matter has been referred to the members of the Truck Division. If it should be the general opinion of the Division that this subject should be taken up, a Subdivision will be appointed to formulate a tentative recommendation.

Oil-Drain Plugs

At the last meeting of the Engine Division the desirability of providing suitable means for easily draining all engine oil-pans was discussed. It was decided that, as the oil-drain is a part that is dependent upon individual engine design, no definite type should be standardized, but that a recommendation could be formulated which would indicate that an oil-drain device should be provided, having a hole of a minimum size located at the lowest part of the oil-pan or crank-case cover. In order that the Engine Division may base its recommendation on the best present-day practice, a questionnaire covering these points has been sent to engine builders and automobile producers who build their own engines.

Silent Chains

At the last meeting of the Chain Division, held jointly with the Committee on Steel Roller Chains of the American Society of Mechanical Engineers and the Committee on Sprockets of the American Gear Manufacturers Association, the subject of silent-chain standardization was brought up, but it was the consensus of opinion that structural differences between makes prevent the adoption of a standard at the present time. It was thought that normal silent-chain development during the next few years will make standardization possible.

It was stated that to obtain interchangeability of silent chains it will be necessary to standardize the pitch, the included angle, the method of guiding, the width, the maximum radial clearance from the joint over the back of the link, the maximum distance from the center of articulation to the point of the link, the perpendicular distance from the bearing face of the link to the center of articulation and the location of the top of the teeth with regard to the chord connecting the centers of articulation. It was emphasized that

the standardization of silent chains is further complicated owing to the actual differences in construction of the chains.

Spark-Plug Hoods

At the last Electrical Equipment Division meeting it was reported that a thorough investigation of the patent situation in connection with spark-plug hoods had been made and that it was claimed that a number of patents in the aggregate cover any practical form of construction. It was therefore decided to discontinue consideration of the standardization of spark-plug hoods.

Storage Batteries

It has been felt that the Standards Committee could be of service to the storage-battery and associated industries in connection with the recent development of a molded hard-rubber storage-battery container. As the molds and equipment for making these containers are very expensive, it seems that the logical procedure for the battery, automobile and hard-rubber manufacturers is to get together and adopt standards relating to the rubber container, before too much money shall have been spent on mold and machine equipment.

A further object of the standardization proposed would be perhaps to guide the automobile builders in adapting their battery compartments to this more compact type of battery,

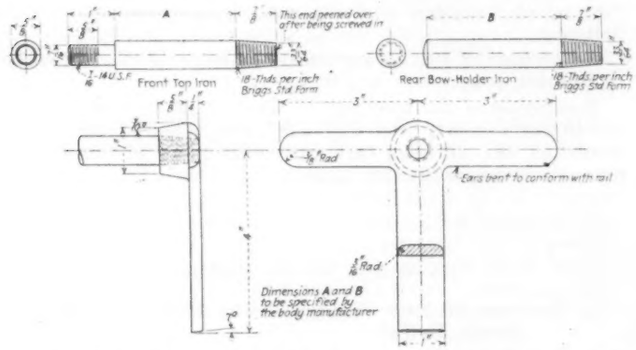
This end peened over after being screwed in
Front Top Iron
18-Thds. per inch Briggs Std. Form
Rear Bow-Holder Iron
18-Thds. per inch Briggs Std. Form
Ears bent to conform with rail
Dimensions A and B to be specified by the body manufacturer

Fig. 1—Through-the-Rail Type of Front and Rear-Top-Iron

so that they and their customers will not be handicapped in the way they have been handicapped in the past when an automobile was put out with a battery compartment of such dimensions as to preclude the use, for either original equipment or renewal, of any but one special make and type of battery.

Another point is the need of a name to distinguish the single-compartment container from the present case and jar. It is stated that the word "container" is not desirable on account of its similarity to the word "retainer" and because it has been used in a general sense already. The words "case," "box," "tray" and "jar" are already used as names of battery parts.

Tank Caps

The following comments in the matter of specifying the minimum size of the filler opening of automobile gasoline-tanks have been referred to the members of the Parts and Fittings Division. The present S.A.E. Recommended Practice for Tank and Radiator Caps, page C58, S.A.E. Handbook, does not specify the minimum size of opening, only the diameter of the threaded portion for both internally and externally threaded filler-openings having been determined upon.

The demand today is for a gasoline pump that will deliver a given amount of gasoline in the shortest possible time. Pumps have therefore been designed for use in service stations with 1¼-in. hose and nozzles.

Complaints are received by pump manufacturers that the nozzles on these pumps are too large to fit into the openings provided in the gasoline tanks on many automobiles. This means that pump manufacturers are obliged to put on a small nozzle, thus restricting the discharge and defeating in a measure the advantages gained from a large pump. If an effort is made to force the delivery with the smaller nozzles, it requires more strength and the gasoline is delivered at a high velocity.

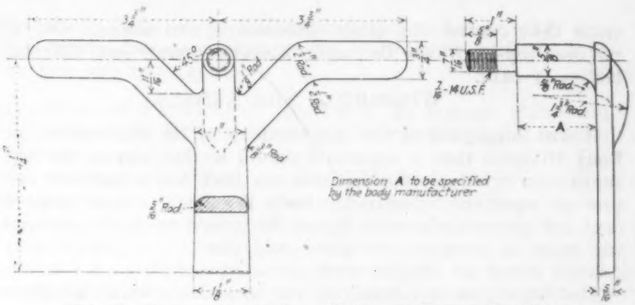

Fig. 2—Through-the-Rail Type of Front Top-Iron

Some automobiles are provided with large openings; 2½ in. is common. This matter should be taken up with the automobile builders as it is to their advantage to provide openings of proper size so that gasoline tanks can be filled quickly.

Sometimes the trouble is due to the connection to the tank being made by a pipe with an offset in it of small diameter. The smallest straight opening that should be used is 2 in. and where the connection is made to the side of the tank by a short pipe with an offset in it, it should be larger with the curve at a greater angle.

Top-Irons

O. H. Clark, who was appointed a Subdivision of one to formulate a recommendation on top irons in February, 1921, recently submitted a tentative report, in connection with which attention is called to Figs. 1, 2 and 3.

This report is based on a survey of present-day top-iron practice, which showed a great variety of types and sizes. A careful analysis of the data, however, indicated that the great majority of top irons are made with 7/16-in.-14 United States Form Threads. This thread has therefore been specified and should meet with general approval. The top-iron types recommended cover all general requirements. The through-the-rail type of front top-iron can be used through the rail by body builders who do not wish to provide for the removal of the top iron in case the permanent or California type of top is used. This type of top iron is superior to the separate through-the-rail type of front and rear top-irons inasmuch as it is not necessary to counterbore such large holes through the rail for the top-iron sockets, avoiding the weakening of the top rail.

This report was discussed at the last Passenger-Car Body Division meeting, but no definite action was taken. It was felt that probably only the threaded shank on the top-iron can be standardized, as there are so many varying condi-

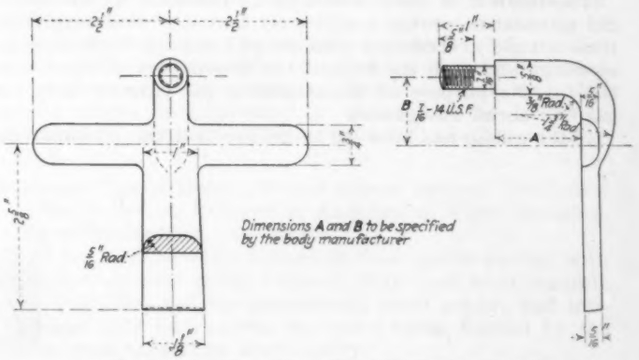

Fig. 3—Over-the-Rail Type of Front Top-Iron

tions that control the other dimensions and shapes, and as no one top-iron can be used interchangeably on different bodies or cars.

Windshield Side-Arms

It was suggested at the last meeting of the Passenger-Car Body Division that a standard should be formulated for the shanks on windshield side-arms, so that body builders can provide standard holes in the body frames. It was thought that the shank diameters should be in odd-number sizes and the holes in even-number sizes, and that there should be a definite series of lengths and threaded ends.

The Society is to circularize the windshield manufacturers for suggestions and data in this connection before further action is taken.

Inch-Type Thrust Ball-Bearings

At the last Ball and Roller Bearings Division meeting criticisms and suggestions in connection with the present thrust-bearing standards that had been submitted to the Society were discussed. It was the consensus of opinion that the present standard should remain as published in the S.A.E. Handbook, it being stated by several members that they are in satisfactory form and use.

Metric-Type Thrust Ball-Bearings

At the Oct. 11 meeting of the Ball and Roller Bearings Division the history of the development of the present metric-type thrust ball-bearing standards, which include only the general types and the ranges of tolerances, was reviewed. The entry of the United States into the recent war necessarily postponed consideration of these standards in co-operation with foreign manufacturers, particularly those in Germany.

A Subdivision, representative of practically all thrust ball-bearing manufacturers, was appointed to consider and report on this subject.

ACTIVITIES OF THE SECTIONS

Schedule of Sections Meetings

JANUARY

6—Washington Section—Aviation Meeting
13—New England Section—Visit to Stanley Plant in Newton, Mass.
17—Buffalo Section — Pneumatic Truck Tire Temperatures — Professor Ellenwood Commercial Aviation—L. B. Lent
26—Pennsylvania Section — Follow-up of Annual Meeting Papers

FEBRUARY

3—Washington Section
3—Mid-West Section — The Constitution of Matter—Prof. H. B. Lemon
8—Minneapolis Section — Road-Building Machinery and Engineering
10—New England Section — Isolated Lighting Plant Meeting at Boston or Worcester. Paper by Mr. Wilkins of the H. C. Dodge Co.
21—Buffalo Section—Resilient Wheels — A. C. Vauclain
23—Pennsylvania Section — Current Business Conditions and the Engineer's Place in the Commercial Development

THE Sections meetings held in December were for the most part devoted to the general subject of commercial aviation. Various phases of this topic were considered at the different meetings by a number of well-qualified speakers.

The interest in these meetings, as indicated by the splendid attendance, proved conclusively that it is necessary from time to time to conduct a widespread campaign both through meetings and with the help of the newspapers of the Country for the purpose of disseminating the current facts regarding aerial navigation.

If the public has been led to believe that the mishaps and accidents of aeronautics are the only side of the picture, it is because too few facts have been given out showing the progress which has been made in safety, regularity of service, and cost.

An account of the various meetings is given in more detail on another page.

A schedule of the meetings of the various Sections for the months of January and February and a list of the Secretaries of the different Sections with their addresses are printed elsewhere on this page.

Secretaries of the Sections

Buffalo Section—George Pettit, 1569 Jefferson Street, Buffalo

Cleveland Section—E. W. Weaver, 5103 Euclid Avenue, Cleveland

Dayton Section—R. B. May, Dayton Engineering Laboratories Co., Dayton, Ohio

Detroit Section—B. Brede, assistant secretary, 1361 Book Building, Detroit

Indiana Section—B. F. Kelly, Weidely Motors Co., Indianapolis

Metropolitan Section—F. E. McKone, 347 Madison Avenue, New York City

Mid-West Section—T. Milton, 140 South Dearborn Street, Chicago

Minneapolis Section—C. T. Stevens, Reinhard Brothers Co., Minneapolis

New England Section—H. E. Morton, B. F. Sturtevant Co., Hyde Park, Boston

Pennsylvania Section — T. F. Cullen, Chilton Co., Market and 49th Streets, Philadelphia

Washington Section—B. R. Newcomb, 211 Victor Building, City of Washington

Publications of Interest *to* S. A. E. Members

In this column are given brief items regarding technical books and publications on automotive subjects. As a general rule, no attempt is made to give an exhaustive review of the books, the purpose of this section of THE JOURNAL being rather to indicate from time to time what literature relating to the automotive industry has been published with a short statement of the contents.

TESTS OF CENTRIFUGALLY CAST STEEL. By George K. Burgess. Bureau of Standards. Technologic Paper No. 192. Published by Superintendent of Documents, Washington. 22 pages.

Six castings manufactured by the Millspaugh centrifugal process were examined as to their physical and chemical properties, including hardness, tensile strength, impact resistance, density, internal stress, segregation, soundness and microstructure, both in the condition as cast and after various heat-treatments. This investigation shows the possibilities of substituting heat-treatment for forging in this type of casting.

NICKEL. Bureau of Standards Circular No. 100. Published by Superintendent of Documents, Washington. 106 pages.

This is one of a series of Bureau of Standards bulletins on metals and alloys in each of which all of the best information resulting from tests and investigations of the metal considered will be grouped. The several physical and chemical properties of nickel are given and the methods of its manufacture and working are outlined. The more common nickel alloys are reviewed and an appendix includes a condensed bibliography on this metal.

SHORT PAPERS FROM THE COOPERATIVE OIL-SHALE LABORATORY. By M. J. Gavin and L. H. Sharp. State of Colorado Cooperative Oil-Shale Investigation Bulletin No. 1, Boulder, Col. 68 pages.

This paper is a presentation of the results of preliminary studies at the Colorado Cooperative Oil-Shale Laboratory by the Bureau of Mines and the State of Colorado. The investigations are for the purpose of determining by large-scale laboratory retorting tests, those conditions that will produce the optimum yield of the best quality of products from Colorado shales. The fuel and total heat values of oil-shale and its products are studied and compared with those of other fuels. The analytical distillation of shale oils from Colorado and Scotland is given with similar data on Pennsylvania crude oil. Data on the weights and composition of shale are included.

ZINC-CYANIDE PLATING SOLUTIONS. By Wm. Blum, F. J. Liscomb and C. M. Carson. Bureau of Standards Technologic Paper No. 195. 19 pp.

During the war zinc plating, or electro-galvanizing, was applied extensively for the protection of steel against corrosion. For this purpose zinc-sulphate or zinc-cyanide solutions can be employed, but the latter produce more uniform distribution of the metal upon irregularly-shaped parts. This paper describes the results of experiments upon the preparation, analysis and operation of zinc-cyanide plating solutions. It was found that in the preparation of such solutions a considerable economy could be effected by the use of zinc oxide to replace part or all of the zinc cyanide commonly used for this purpose. Complete formulas and operating directions are given for the use of these plating solutions. It is believed that the information may be of considerable value in facilitating the use of zinc protective coatings, either alone or as a foundation for nickel or other finishes where both appearance and permanent resistance to corrosion are important.

ECONOMICS OF PETROLEUM. By Dr. J. E. Pogue. Published by John Wiley & Sons, New York City. 375 pages; numerous tables and charts.

In presenting the Economics of Petroleum, Dr. Pogue has rendered an important service to the many industries in the development of which petroleum or its products play an important part. We find collected in this volume a mass of data and a careful analytical discussion of the topic, which should be in the hands of all who are concerned with the economic phase of the petroleum problem. The author has used excellent judgment in the selection of material and, after prefacing each chapter with a concise statement of the general aspect, has presented this material in carefully devised charts and tables that are pleasing to see and easily understood. The discussion is presented in a terse and readable style and is confined closely to the topic in hand. There is of course considerable necessary repetition involved in the introductory paragraphs to each chapter. The treatise is creditable for its unbiased presentation of facts and logical deductions, as well as for the absence of bias on controversial topics.

The chapter on the motor-fuel problem is of particular interest to the automotive industry, as are other chapters devoted to specific industries, in particular that on the relation of the coal industry to the oil industry. The international features of the situation are covered with some care.

THE AGRIMOTOR, PRESENT FAILINGS AND FUTURE PROSPECTS. By H. Scott Hall and H. G. Burford. Paper read before the Institution of Automobile Engineers, 28 Victoria Street, Westminster, S.W., London, England. 17 pages.

The authors endeavor to give their ideas of the development of a true agrimotor. The discussion traverses the lines of natural argument and development that have been passed over in America, including the influx of automobile ideas resulting in the conclusion that the agrimotor finally will not be an automobile but a special new machine requiring a thorough knowledge of, and design in accordance with, a different set of facts and data. A review is given of the evident advantages of the tractor over the horse with regard to fatigue and time of accomplishment, and doubt expressed as to whether the plow as now made is the ultimate solution of soil operation or whether the separate plow and tractor are ideal. The authors believe that the tractor is not necessarily the correct idea as compared with the possible outfit, the agrimotor that covers all operations, and consider whether the machine should be a combined hauling and field operating machine.

Questions of weight, speed, hitching and line of draft are sketched from the British point of view, in which it seems a task to eliminate the extra man on the plow and make the outfit a one-man unit as has been the case in America for years. The difficulties of meeting the wide range of row-crop spacings lead through an intricate suggestion of telescoping axles and means for rapid change of overall widths, and this develops again the query, Are we spacing our crops right?

The authors believe the ultimate agrimotor will be distinctly a field machine. The complexities of the differential gear are treated, the conclusion being reached that this element should be eliminated or designed to be locked in straightaway operation. The paper is well worth reading.—O. B. Z.

HIGHWAYS GREEN BOOK. Second annual edition. Published by the American Automobile Association, Riggs Building, City of Washington. 480 pages.

This is an informative volume in three parts dealing with road improvements under Federal, State and local control; the construction and maintenance of rural roads; and miscellaneous data and tables, the topics being treated by the leading road experts of the Country.

Part 1 gives a résumé of highway legislation, the Federal Aid Road Act and progress thereunder and matter descrip-

tive of highway management and financing in the various States, together with an analysis of the Townsend bill and an intensive presentation of the arguments for good roads. The drainage of roads and the future reinforced concrete highway for 30-ton traffic are subjects of special interest in Part 2, among others. A résumé of highway engineering educational courses is included in Part 3, and among other interesting features are reports of traction tests showing the economy of improved roads; motor-car, truck and motorcycle registrations and gross receipts therefrom for 1920; and the registrations of cars and trucks for 9 years. A bibliography of roads and allied subjects is presented and tables stating the weights and measures of road materials are given.

DESIGN AND MANUFACTURE OF PNEUMATIC TIRES FOR MOTOR VEHICLES. By Colin Macbeth. Paper read before the Institution of Automobile Engineers, 28 Victoria Street, Westminster, S.W., London., England. 102 pages.

The author discusses pneumatic-tire functions broadly, in order of importance, as being inclusive of provisions for (*a*) comfort, in allowing high speeds on poor surfaces such as can be obtained only when using wheels having a yielding periphery; (*b*) safety, in providing a sure grip on all conditions of road surface when driving, but particularly when accelerating, braking and cornering; (*c*) reliability, in protecting the air container from penetration by road obstacles; (*d*) durability, in insuring long mileage and failure only because of wear and tear; (*e*) accessibility, in making it reasonably easy to fit and to remove tires whenever necessary; and (*f*) efficiency, in the securing of the absorption of the minimum amount of engine power.

The features limiting the scope of the designer and the details that allow him scope are commented upon under four and five divisions respectively, the characteristics of the rubber mixings used being mentioned under degrees of hardness and vulcanization, their disposition and their volumetric and area costs. The quality and disposition of metal parts, molding and vulcanizing systems and types of rim are discussed at some length and illustrated, prefatory to a description of how a pneumatic tire of the well-known type is designed and manufactured, its specification being given first.

Design is detailed under considerations of tire beads, rim tolerances and rim types, bead cores, casing dimensions, rolling factors, tread and casing resistance to obstacles and the effect of inflation on the tire surface in contact with the road.

Tire manufacture is described under headings that include the preparation of the canvas and the rubber and subdivisions comprehensive of the entire process, copious illustrations being supplied throughout the paper and a lengthy discussion of it being appended.

MOTOR TRUCK TRANSPORTATION. By F. Van Zandt Lane. Published by the D. Van Nostrand Co., New York City. 153 pages; 50 illustrations.

The author has written an interesting treatise on the simpler economic phases of motor-truck transportation that should be of value particularly to readers who are interested in establishing cost-accounting systems for truck operation. It is recognized by the author that the numerous factors in the cost of operation depend so much on local conditions that an attempt to give even illustrative figures is likely to be misleading; hence he confines himself wisely to a rather careful analysis of what these factors are and how they may be taken into consideration in accounting systems. He gives for comparison also a similar analysis, without figures, for costs of horse-drawn traffic and railroad traffic.

The critical reader gains the impression that, while the author has carefully enumerated all the apparent factors of cost, his failure to evaluate these factors has led to a somewhat exaggerated endorsement of the almost universal superiority of the motor truck for a very wide range of conditions, in spite of numerous warnings that he has included against this attitude. The later chapters of the volume afford an interesting review of developments in bodies, loading devices, maintenance methods and trailers, and a discussion of solid and pneumatic tires, the special problems of the farmer, and the economic possibilities of good highways.

CRIPPLING STRENGTH OF AXIALLY LOADED RODS. By Fr. Natalis. Translated from Technische Berichte. National Advisory Committee for Aeronautics Technical Note No. 31. Published by the National Advisory Committee for Aeronautics, Washington. 34 pages.

The formulas hitherto employed for the calculation of rods subject to compression, are usually of value only for stout or slender rods. A new empirical formula has been developed in this article, which holds good for any length and any material of the rod, and agrees well with the results of extensive strength tests. Tables giving the crippling load for solid and hollow sectioned wooden rods and steel tubes of different thickness and length are included. A graphical method of calculation of the breaking load is derived in which a single curve is employed for determining the allowable fiber stress.

TEST OF A STANDARD LIBERTY-ENGINE CYLINDER MOUNTED ON A UNIVERSAL ENGINE CRANKCASE. Air Service Information Circular, Vol. II, No. 199. Published by Chief of Air Service, Washington. 10 pages.

This test was conducted to obtain the power, friction losses, temperatures and heat transfer characteristics of the standard Liberty-engine cylinder when mounted on the McCook Field universal test engine crankcase. It was concluded that the brake-horsepower output of a multi-cylinder engine can be safely estimated to be, at the normal range of operation, the product of such output of a single cylinder on the universal engine and the number of cylinders. Neither the fuel consumption nor the indicated horsepower output is so comparable, however.

Interesting tables of test data are included which show that at 1500 r.p.m. the maximum brake mean effective pressure was 122 lb. per sq. in.; the mechanical efficiency, 80 per cent; and the fuel consumption, 0.64 lb. per b.hp-hr. Careful analysis was made of the mechanical losses as determined in the test.

Applicants *for* Membership

The applications for membership received between Dec. 1 and 20, 1921, are given below. The members of the Society are urged to send any pertinent information with regard to those listed which the Council should have for consideration prior to their election. It is requested that such communications from members be sent promptly.

AHLERS, MILTON THEODORE, assistant engineer, City Machine & Tool Works, *Dayton, Ohio.*

ALAND, RICHARD C. J., engineer, Thermatic Oil Refiner Co., *Detroit.*

BASSETT, CYRUS W., sales engineer, Bethlehem Steel Co., *Bethlehem, Pa.*

BRIAN, ERNEST, coach superintendent, Detroit-Cadillac Motor Car Co., *New York City.*

BROAD, ROBERT ELTON RODMAN, student, Armour Institute of Technology, *Chicago.*

BROWN, GARNET C., sales engineer, L. H. Gilmer Co., *Tacony, Philadelphia.*

BURSIK, FRANK JAMES, student, Armour Institute of Technology, *Chicago.*

CANAVAN, J. JEROME, transportation engineer, 619 Chapman Building, *Los Angeles, Cal.*

CORBIN, ERNEST L., student, Purdue University, *Lafayette, Ind.*

CROSSMAN, S. B., assistant service engineer, Detroit-Cadillac Motor Car Co., *New York City.*

DOMJAN, RALPH, tool designer, service department Detroit-Cadillac Motor Car Co., *New York City.*

EBERHART, CLEBURNE, JR., president, Eberhart Steel Products Co., Inc., *Buffalo.*

ELLISON, LUKE V., automotive service, Ellison Service, *South Deerfield, Mass.*

ENGBRECHT, HERMAN J., service manager, National Motor Sales Co., *Chicago.*

FEZANDIE, EUGENE, student, Columbia University, *New York City.*

FISCHER, KARL W., automobile repair foreman, Detroit-Cadillac Motor Car Co., *New York City.*

FOLTZ, HAROLD H., president and general manager, Foltz Truck Service Co., *Akron, Ohio.*

FOSTER, J. P., superintendent, Maui Agricultural Co., *Paia, Maui, T. H.*

GERMAN, JOHN WESLEY, assistant treasurer, Detroit-Cadillac Motor Car Co., *New York City.*

GREENHOE, CLAUDE, engineer, Hyatt Roller Bearing Co., *Detroit.*

HAINES, W. S., experimental engineer, Mercer Motors Co., *Trenton, N. J.*

HAMMERL, JACOB, body engineer, Packard Motor Car Co., *Detroit.*

HAWKINS, PAUL I., department foreman, C. L. Best Gas Traction Co., *San Leandro, Cal.*

HO, YAO, draftsman, Baldwin Locomotive Works, *Philadelphia.*

HUGGINS, E. MELVILLE, chief engineer, Snead & Co., *Jersey City, N. J.*

JOHANNESSON, R., sales director, Textileather Co., 1819 Broadway, *New York City.*

JONES, LESTER G., student, Columbia University, *New York City.*

JONSSON, JOHN ERIK, student, Rensselaer Polytechnic Institute, *Troy, N. Y.*

KEARNS, CHARLES M., general manager, Kearns-Dughie Motors Corporation, *Danville, Pa.*

KIMBELL, ARTHUR W., secretary and general manager, Cinch Fastener Corporation, *Chicago.*

KOELBLE, EDNA O'CONNOR, 370 Manhattan Avenue, *New York City.*

KOHL, J. J., assistant manager, City Machine & Tool Works, *Dayton, Ohio.*

KOPSHAC, J. C., general mechanical superintendent, Detroit-Cadillac Motor Car Co., *New York City.*

KUKELKORN, GEORGE A., final inspector, Detroit-Cadillac Motor Car Co., *New York City.*

LARSON, V. L., chief draftsman, E. F. Norelius, 430 Andrus Building, *Minneapolis.*

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LEIGHTON, WILLIAM E., auto inspector, Detroit-Cadillac Motor Car Co., *New York City.*

LENT, LEON B., engineer, Aerial Transport Corporation, *New York City.*

LILLIBRIDGE, H. W., engineer, Atwater Kent Mfg. Co., *Philadelphia.*

LORENZ, HARRY H., technical shop consultant, Detroit-Cadillac Motor Car Co., *New York City.*

MARQUIS, ALBERT C., salesman, Rauh's Tire & Auto Supply Co., *Dayton, Ohio.*

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MESSINGER, CARL W., Detroit sales representative, Stanley Works, *New Britain, Conn.*

NISSAR, A. R., deputy head, Central Technical Institute, *Byculla, Bombay, India.*

NOFSINGER, CHARLES W., student, University of Illinois, *Urbana, Ill.*

OHSAWA, GEN, student, University of Illinois, *Urbana, Ill.*

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PHELAN, HERBERT C., tool-salesman, Cornwell-Quality-Tools Co., *Cuyahoga Falls, Ohio.*

PLASTERER, KENNETH C., foreman of machine shop inspection, Midwest Engine Co., *Indianapolis.*

REIHMER, LEO LESTER, student, Armour Institute of Technology, *Chicago.*

REUTER, IRVING J., general manager, Remy Electric Division, General Motors Corporation, *Anderson, Ind.*

RICE, HERBERT H., president and general manager, Cadillac Motor Car Co., *Detroit.*

RIEGER, EARL CHARLES, student, Armour Institute of Technology, *Chicago.*

RUSSELL, ALBERT J., distributor for Dorris Motor Car Co., *Los Angeles, Cal.*

RYDER, C. D., chief engineer, Corcoran Victor Co., *Cincinnati.*

SHOEMAKER, HARRY, salesman, Girard Automobile Co., *Philadelphia.*

TICHBORNE, WALTER F. C., resident manager, Detroit-Cadillac Motor Car Co., *New York City.*

TROAKE, SAMUEL S., chief inspector, Detroit-Cadillac Motor Car Co., *New York City.*

WALTER, GEORGE MARTIN, manager parts service department, Detroit-Cadillac Motor Car Co., *New York City.*

WINQUIST, GEORGE WALTER, student, Rensselaer Polytechnic Institute, *Troy, N. Y.*

WOOD, HENRY M., secretary, Trailmobile Co., *Cincinnati.*

Applicants *Qualified*

The following applicants have qualified for admission to the Society between Nov. 10 and Dec. 10, 1921. The various grades of membership are indicated by (M) Member; (A) Associate Member; (J) Junior; (Aff) Affiliate; (S M) Service Member; (F M) Foreign Member; (E S) Enrolled Student.

ALLAN, ROBERT K. (F M) chief draftsman, Skefko Ball Bearing Co., Ltd., *Luton, Bedfordshire, England.*

ANDERSON, RALPH W. (E S) student, Buffalo Technical High School, *Buffalo,* (mail) Apartment 14, The Matthewson, 294 South Elmwood Avenue.

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CHENOWETH, OPIE (J) field man, Peoples Loan & Trust Co., *Winchester, Ind.,* (mail) 335 East Washington Street.

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GIRDLER, LOUIS T. (A) secretary and treasurer, Standard Automotive Parts Co., *Muskegon, Mich.*

GRANDSTAFF, BEN F. (A) manager, repair parts department, Munger Automobile Co., *Dallas, Tex.,* (mail) 121 Foster Street.

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NEELANS, HAROLD G. (E S) R.F.D., *Hazardville, Conn.*

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SCHAUFELE, WILLIAM H., JR. (J) layout draftsman, O. Armleder Co., Cincinnati, (mail) Fairfield and Washington Streets, *Bellevue, Ky.*

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WATANABE, SABRO (F M) Nihon Tokushuko Co., *Omori, Tokyo, Japan.*

WING, WILFORD W. (J) service engineer, service department, Frigidaire Corporation, *Dayton, Ohio.*